

STRESS CONCENTRATION  
IN A BEAM WITH A  
REINFORCED ELLIPTICAL  
DISCONTINUITY

BY

TERRIL ALEXANDER EFIRD  
ANDREW HOMER SKINNER, JR.

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Professor Joseph S. Newell  
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Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Sir:

I, Terril A. Efird, in accordance with the requirements for the degree of Naval Engineer, and I, A. Homer Skinner, Jr., in accordance with the requirements for the degree of Master of Science in Naval Architecture, submit herewith a thesis entitled "STRESS CONCENTRATION IN A BEAM WITH A REINFORCED ELLIPTICAL DISCONTINUITY."

Respectfully,



STRESS CONCENTRATION IN A BEAM  
WITH A REINFORCED ELLIPTICAL DISCONTINUITY

BY

TERRIL ALEXANDER EFIRD  
Lieutenant, U. S. Navy  
B. S. University of  
California, 1942

ANDREW HOMER SPINNER, JR.  
S. B. Massachusetts  
Institute of Technology,  
1942

Submitted in Partial Fulfillment of the  
Requirements for the Degrees

of

NAVAL ENGINEER

AND

MASTER OF SCIENCE IN NAVAL  
ARCHITECTURE

Respectively

at the

Massachusetts Institute of Technology

These  
= 26

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SUMMARY

This report investigates experimentally the stresses occurring around one quadrant of a centrally-located reinforced elliptical discontinuity in a steel I beam subjected to pure and complex bending. The reinforcement, in the form of a flat bar ring, is varied from an excess breadth to as small a breadth as possible at a constant thickness approximately equal to that of the web. For each reinforcement the beam was tested in pure bending and at three ratios of average shear stress to maximum bending stress at the section of the opening as calculated for the intact beam. The stresses at seventeen selected points in the web, reinforcement and flanges were derived from strains observed from Baldwin SR-4 electrical strain gages in conjunction with "stresscoat" diagrams. Stress concentrations are expressed by the stress concentration factor, defined as the ratio of the observed stress at any point to the calculated principal stress at the point in the intact beam.

The principal results are

1. Stress concentrations of considerable magnitude do exist in the reinforcing ring and in the web adjacent to the discontinuity.
2. Stress concentration factors in the web at the neutral axis are large and vary directly with breadth of ring and inversely with ratio of shear stress to bending stress.





3. Stress concentration factors in the reinforcing ring vary directly with ratio of shear to bending stress and inversely with breadth of ring. They are little affected by breadth of ring below breadths of 7 times the web thickness, where the factor has a value of 1.61, but show a rapid increase as breadth of ring is decreased further.

4. For the dimensions of elliptical opening tested (minor axis equal to 0.4 depth of beam, major axis equal to 1.5 minor axis before reinforcement added), stresses in the flanges are little affected by the opening, reinforced or unreinforced.

5. The greatest observed value of the stress concentration factor, 3.04, occurred in the web at the neutral axis.

6. It was found that increased shear caused a marked increase in the values of the stress concentration factor in the reinforcing ring over those for pure bending, with the result that yielding would take place first in the ring.

The recommendation is made that the breadth of reinforcing rings around elliptical openings in beam webs be made not less than 7 times the thickness of the web, where the ring thickness is the same as that of the web.



## II

### INTRODUCTION

Discontinuities, either for the purpose of weight reduction or access, occur frequently in such ship structural members as floors, frames, deck beams and longitudinals. In practically every instance the member is loaded as a beam in complex bending, i. e. with the presence of both shear and bending. In the case of longitudinals, axial tensile and compressive forces are also present. It has long been recognized that stress concentrations exist around discontinuities in plates and as a plate is more readily subjected to mathematical analysis, several theoretical solutions have been made. In recent years, various investigators have given thought to the problem of the beam, making use of the analysis of the plate.

That the effect of peripheral reinforcement about a discontinuity was to reduce the stress was shown photoelastically by Ruffner and Schmidt (1)\* for reinforced and non-reinforced centrally-located web cut-outs in a beam subjected to both shear and bending. Timoshenko (2) made an approximate solution of the stress distribution in a plate with a circular opening, reinforced by a face plate or bead of welding, subjected to uniform tension. He found that the cross section of the bead

---

\*Numbers in parentheses indicate references in the Bibliography.



was the determining factor and that the larger the cross section of the bead, the smaller the stress concentration became. A bead in the form of two angle bars gave the same results as a bead consisting of a flat plate alone.

Sezawa and Kubo (3), conducting their investigations with the use of gelatine models with reinforced circular openings under tension, found that there was a stiffening ring width beyond which, if it were increased, no further reduction in the stress concentration was obtained. Experiments made by Ballinger and Obermeyer (5) of the tensile stress distribution around a reinforced ovaloid opening (consisting of two semi-circles joined by a parallel section) indicated the presence of concentrations at the juncture of the circular arcs and the parallel section.

A theoretical solution for an ovaloid opening in the web of a beam subjected to pure bending was obtained by Joseph and Brock (6). Their results are shown by the dashed line in Figure VII.

A theory of notch stress, developed by Neuber (7), gives a solution for a small elliptical hole in a bar subjected to complex bending, the axis of the bar being parallel to the major axis of the ellipse. With an elongated ellipse of small dimensions relative to the width of the bar, he states that the increase of local stress is essentially due to the presence of shear.





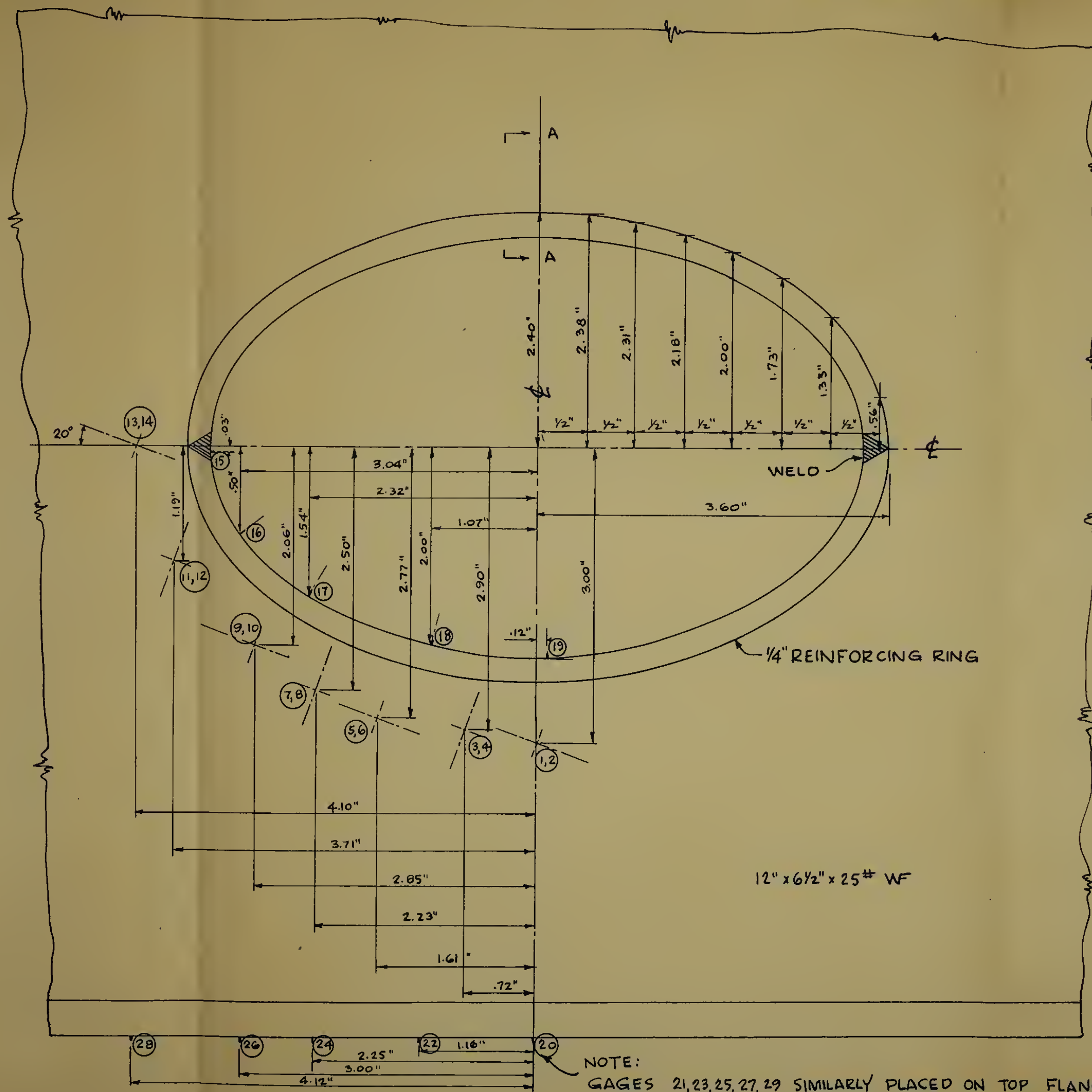
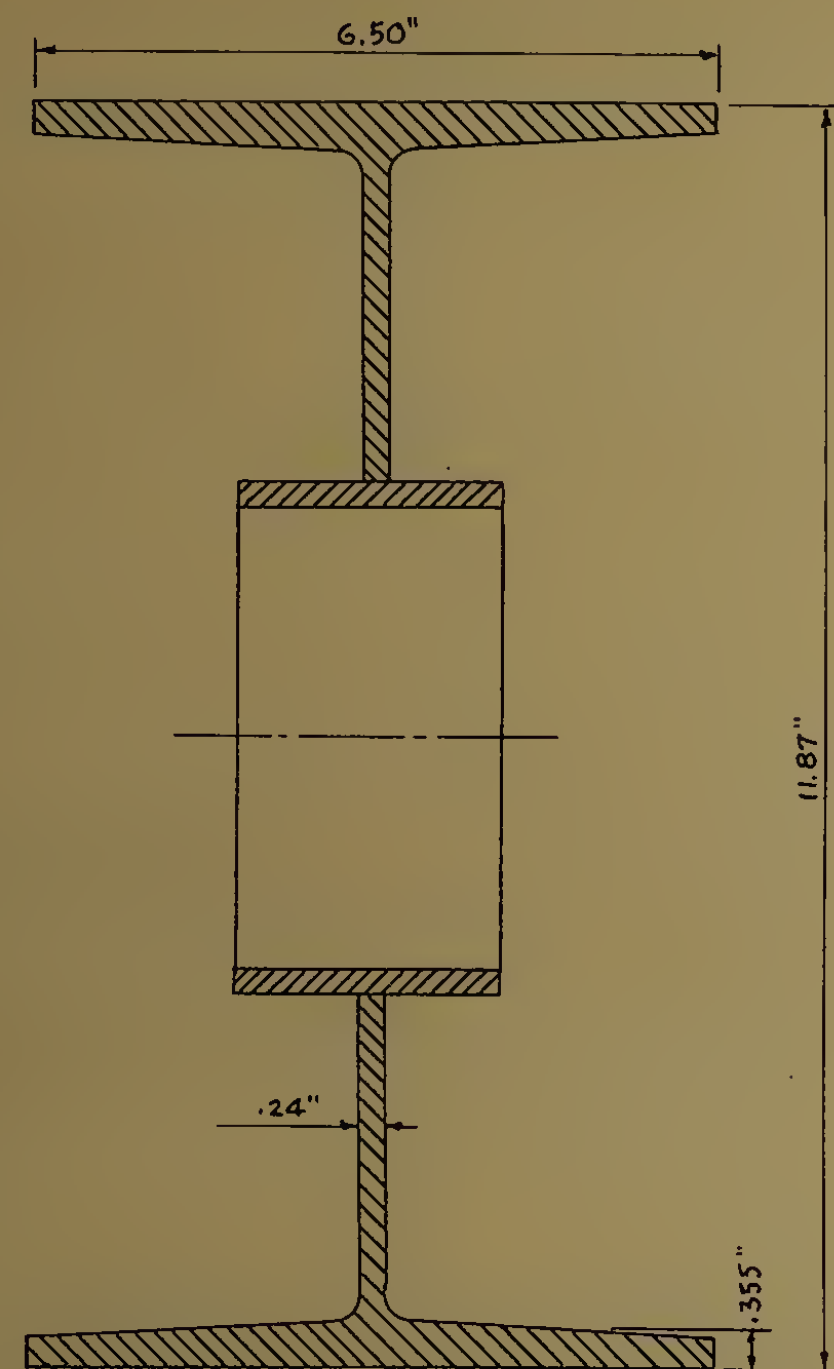
Since the majority of previous investigators of this subject have dealt only with the conditions of uniform tension or pure bending, which are only approximations to the actual loading encountered by the structural member in a ship, the subject selected for the present study is a beam having a central elliptical discontinuity of variable reinforcement loaded in complex bending, (Figure I). The elliptical shape was chosen for the purpose of comparing its concentrations with those of the ovaloid. The reinforcement was varied from an excess amount to as small a value as practicable in order to ascertain whether the results of Sezawa and Kubo (3) would hold for complex bending. To indicate the relative degree of shear and bending for any particular condition of loading, the parameter  $\tau/\sigma$ , the ratio of the nominal shear stress to the maximum bending stress at the section, is used.  $\tau$  is here defined as the shear at the section divided by the product of the depth of the beam by the thickness of the web.  $\sigma$ , represents the bending stress at the extreme fibre. For the calculation of these ratios, the intact beam is used.

The application of the electrical wire strain gages to an eleven foot steel model was deemed the most expedient method of attaining the desired results for this three-dimensional problem. The thickness of the reinforcement was held constant while the breadth was reduced in five successive steps to the least possible amount allowed by the presence of the gages themselves. For all tests the beam was simply supported in



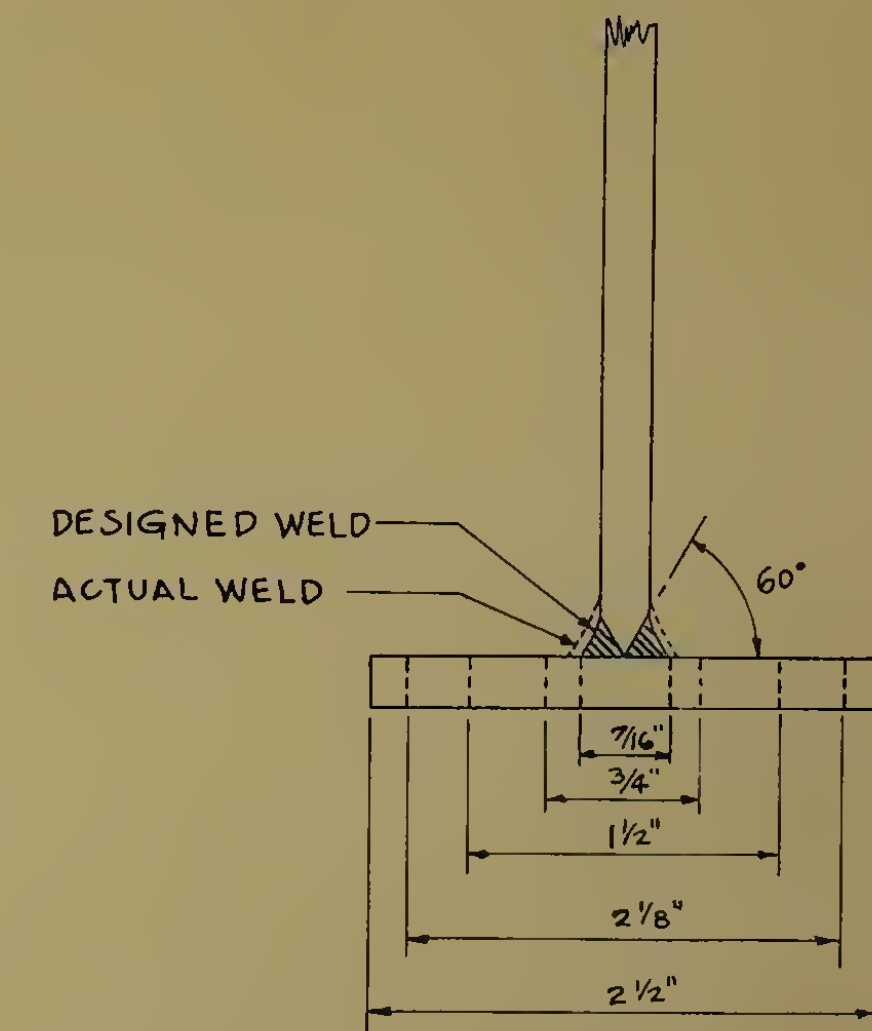
the Riehle 100,000 Pound Testing Machine shown in Figures III - VI. Strain measurements under the loading conditions shown in Figure II were made on the surface of the stiffening ring, on both sides of the adjacent web, and on the flanges by gages located as in Figure I. Stress concentration factors were obtained for each gage location.





GENERAL NOTES -

1. GAGES NOS. 1 THROUGH 14 LIE ON THE SURFACE OF THE WEB, ODD NUMBERS ON ONE SIDE, EVEN NUMBERS ON THE OTHER.
2. GAGES NOS. 15 THROUGH 29 LIE IN THE LOCATIONS SHOWN IN THE VERTICAL CENTERLINE PLANE OF THE BEAM.
3. ALL GAGES BALDWIN SR-4 TYPE A-8.



SECTION  
"A-A"

SHOWING WIDTHS OF REINFORCING RING TESTED

FIGURE I

PLATE I

*W.P.*  
*D.A.B.*

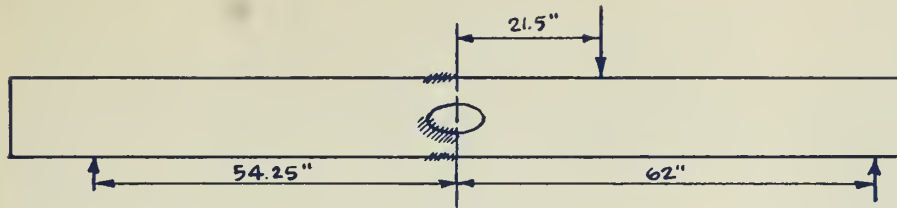
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LOCATION OF GAGES

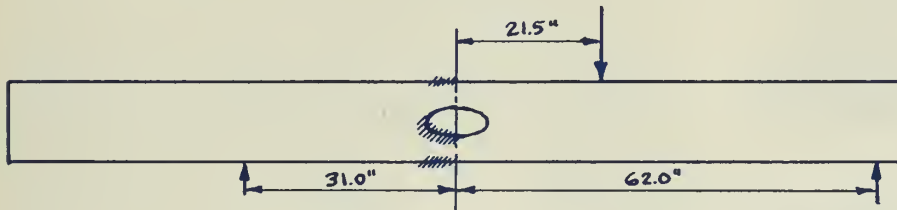




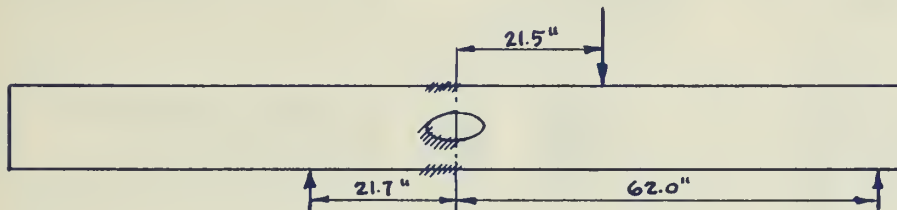
Figur e II



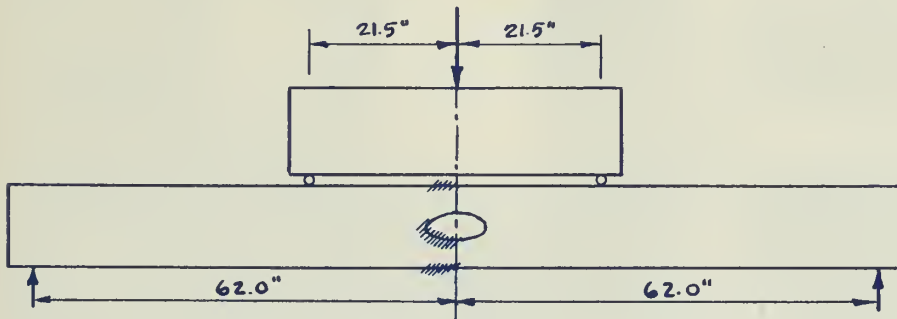
$$\frac{\tau}{\sigma} = .20$$



$$\frac{\tau}{\sigma} = .35$$



$$\frac{\tau}{\sigma} = .50$$



PURE BENDING

LOADING DIAGRAM  
AREA STUDIED SHOWN SHADED

APRIL 26, 1950

A.M.S.  
J.Q.E.







Pump Set for Air Pumping.





Figure IV

Close Up of Beam in Pure Bending.





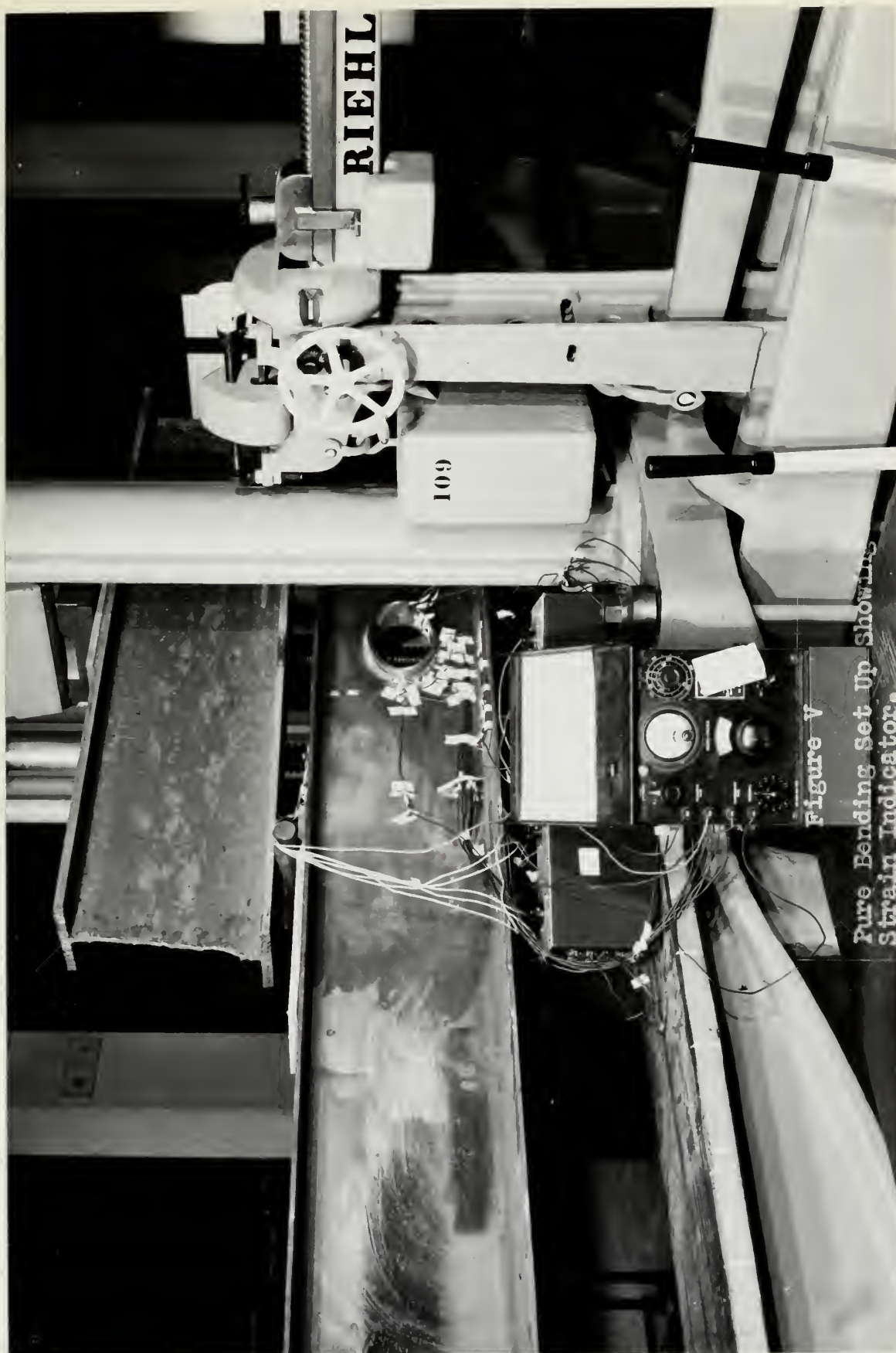


Figure V  
Pure Bending Set Up Showing  
Strain Indicator.



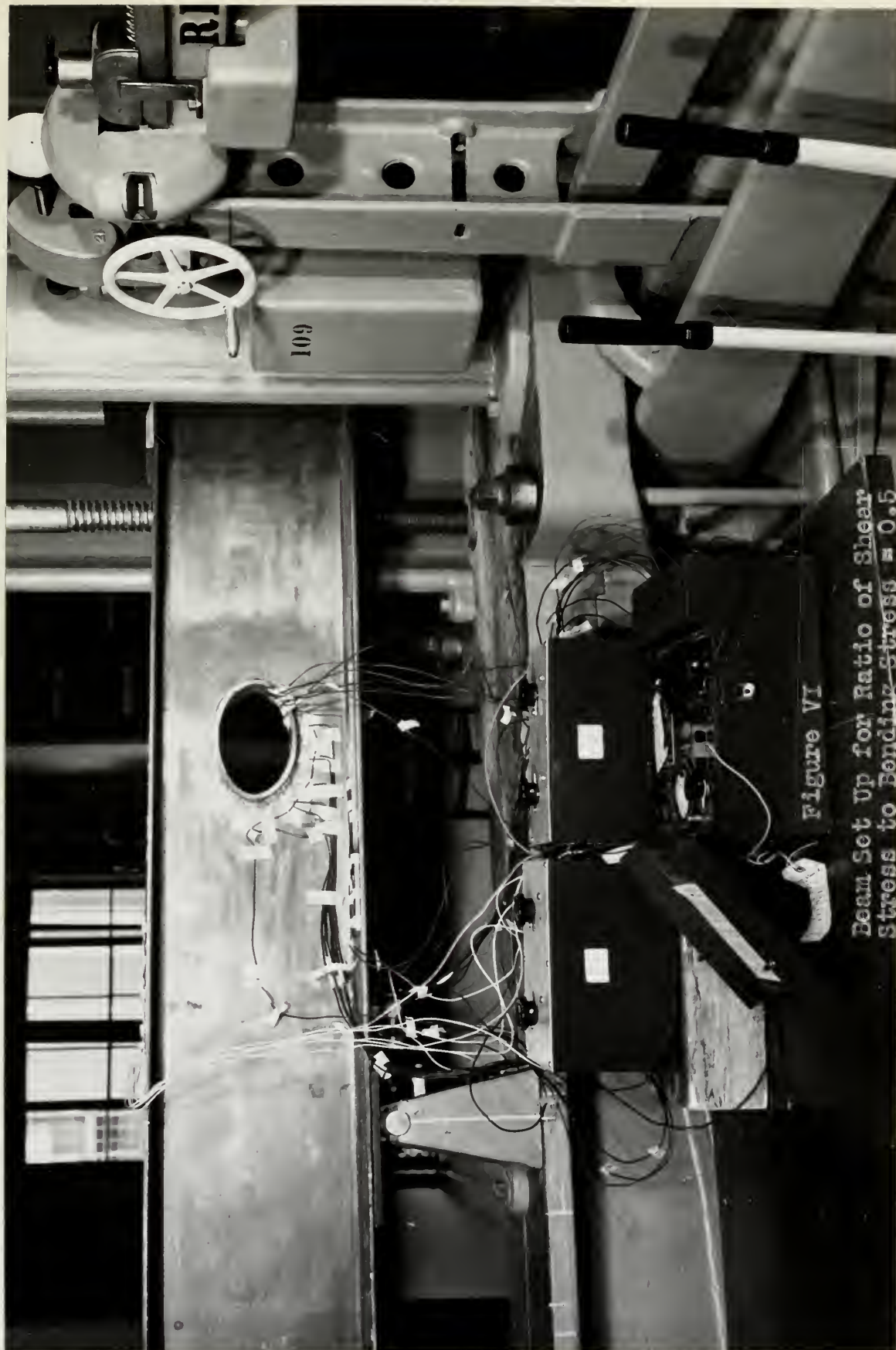


Figure VI  
Beam Set Up for Ratio of Shear  
Stress to Bending Stress = 0.5





### III

#### PROCEDURE\*

A suitable beam was selected, which, due to its modulus and length and by variation in the location of supports and load, would produce ratios of nominal shear stress to bending stress ( $\tau/\sigma$ ) between 0.2 and 0.5 at the center of the section to be investigated. Ratios of shear stress to bending stress of 0.2, 0.35, and 0.5, as well as pure bending, were chosen as one of the parameters of the investigation. The second parameter was the variation in width of the flat bar stiffening ring installed as shown in Figure I. Five widths of stiffening ring were tested.

The beam used for the test was a 12" x 6 $\frac{1}{2}$ " x 25# wide flange high tensile steel beam eleven feet long. The high tensile steel permitted greater loads to be applied to the beam and consequently produced greater strains, thus tending to reduce errors in strain measurement.

The  $\frac{1}{4}$ " x 2 $\frac{1}{2}$ " mild steel flat bar stiffening ring was welded into the elliptical hole in which the ratio of depth to length was 1.5. The depth of the hole before installation of the stiffening ring was 0.4 times the depth of the beam. After all welding was completed on the

---

\*Details of procedure are given in Appendix A.



beam, it was stress relieved by being heated up to 1125°F, held at that temperature for 1 hour, and allowed to cool in the furnace.

Standard flat plate tensile specimens were made to determine the modulus of elasticity of the beam and the stiffening ring.

Since the strains induced in the section under investigation were to be measured by Baldwin SR-4 Strain Gages, it was essential to determine their proper location and orientation in order that the most information be obtained with the least number of gages. A series of stress coat tests were performed to gain this information and are recorded in Figures XV through XVII. Stress coat is a brittle coating which cracks along lines normal to the principal tensile strains.

Type A-8 strain gages were used throughout the test because of their small size and short gage length (1/8 inch). This was necessary in order to obtain a number of strain readings in the web adjacent to the stiffening ring where space was limited, and, in the stiffening ring itself.

The strain gages were cemented to the beam and allowed to dry for a week before being used. Gage locations and orientation are shown in Figure I.

The strain gages were connected as shown in Figure XLII with one compensating gage used in conjunction with all the active gages to take account of temperature effects. Switching from one active gage to the other was accomplished by using two Baldwin 20 point switching units. Strains were measured directly in micro-inches per inch with a Baldwin Portable Strain Indicator, Model K.



For each stiffening ring width the beam was loaded successively as shown in Figure II by the Riehle 100,000 pound testing machine pictured in Figures III thru VI. The three tests for ratios of shear stress to bending stress plus the pure bending test gave four points to be used in plotting the results of the tests. For each loading condition, the zero reading was taken for each gage, then the load applied in four increments to the maximum load, and then reduced by the same increments. Strain readings were recorded for each increment of load increasing and decreasing as well as the initial and final zero readings in order to check the reliability of the gages.

The stiffening ring width was reduced by clamping the beam, with the web horizontal, in a shaper, then cutting transversely across the ring from one side to the other. This method proved very effective, since the rate of cutting was slow enough that the heat generated was insufficient to adversely affect the installed strain gages.

The stiffening ring was reduced in successive steps to  $7/16$ " which was as narrow as it could be made without risking damage to gages installed on the stiffening ring and on the web.

After completion of all tests, the web gages were removed and another stress coat test was made for a shear stress to bending stress ratio = 0.5 in order to determine how nearly the strain cracks conformed to those originally obtained with the stiffening ring width  $2\frac{1}{2}$  inches. These results are shown in Figure XVIII and are superimposed for comparison on the original data as shown in Figure XV.



The stress concentration factors determined in this experiment are obtained by dividing the experimental value of stress by the calculated principal stress at the same point in the intact beam.





#### IV

#### RESULTS

The results of this investigation are embodied in Tables I-V, inclusive; Figures VII to XIV-D, inclusive; and Figures XV-XVIII, inclusive.

Tables I-V give the value of the principal stress derived from the observed strains for every gage location and each condition of loading. These are compared with the calculated principal stress for the same point by means of the stress concentration factor, which is defined as the ratio of the derived stress for the beam with the reinforced discontinuity to the calculated stress for the intact beam.

Figures VII to XIV-D are graphical representations of the results incorporated in Tables I-V, and show the variation of stress concentration with the two basic parameters: (1) breadth of stiffening ring, and (2) ratio of the nominal shear stress to the maximum bending stress ( $\frac{\tau}{f}$ ) taken at a section coincident with the vertical centerline of the ellipse, for the intact beam. Nominal shear stress is defined as the shear force at the section divided by the product of the depth of the beam times the thickness of the web. For the stiffening ring, results are first presented, in Figures VIII, IX, and X, by graphs of stress concentration factor as a function of distance along the elliptical arc of the stiffening



ring surface measured from the vertical centerline. Figures XI and XII, which are the cross curves of Figures VIII, IX, and X, show the variation of the factor with the two basic parameters. For the web, the value of the factor as found in Tables I-V for gages 13 and 14 is plotted against the two basic parameters. These gages were selected because only minor stress concentrations were found to be present at all other web gage locations, except for the smallest breadths of stiffening ring.

Figures XV, XVI, and XVII, in Appendix D, show the lines of the cracks in the stress coat for load conditions  $\frac{\tau}{\sigma} = 0.20, 0.50$ , and pure bending. From these diagrams,  $\theta$ , the angle between the axis of the gage and the principal tensile strain (the orthoronal trajectories of the crack lines), was determined. The values of  $\theta$  for  $\frac{\tau}{\sigma} = 0.35$  were obtained from those for 0.20 and 0.50 by linear interpolation.





Figure VII

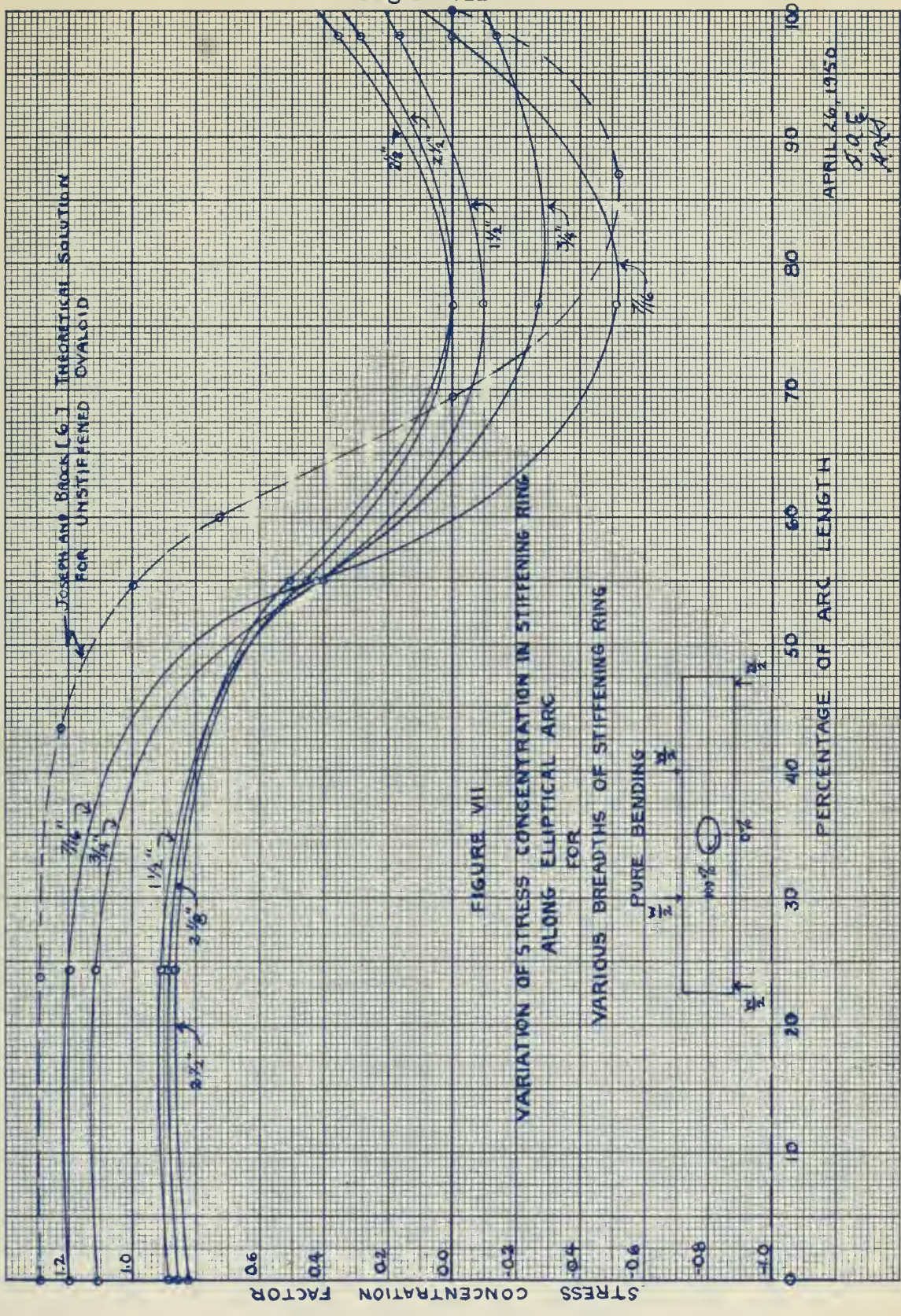






Figure VIII

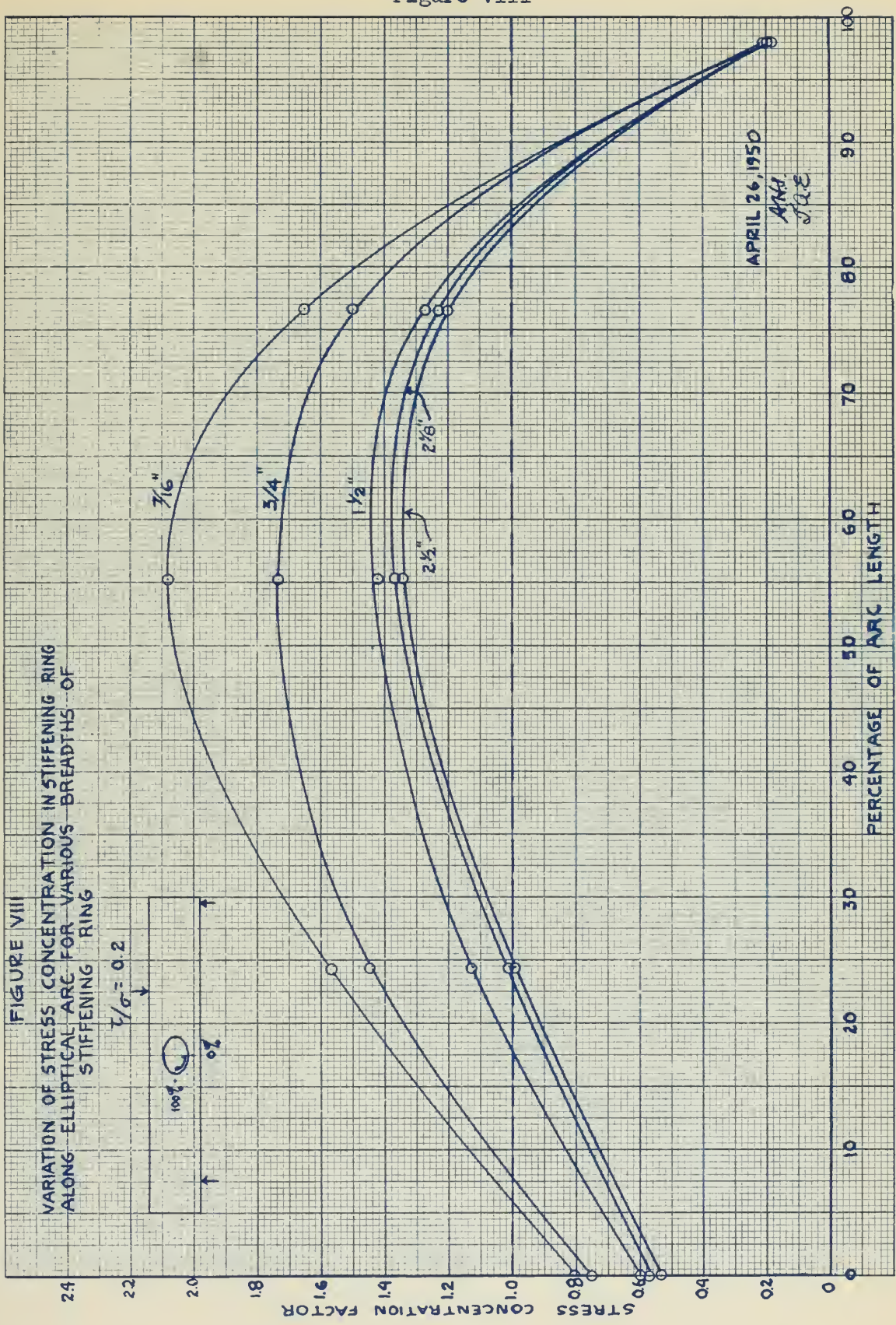






Figure IX

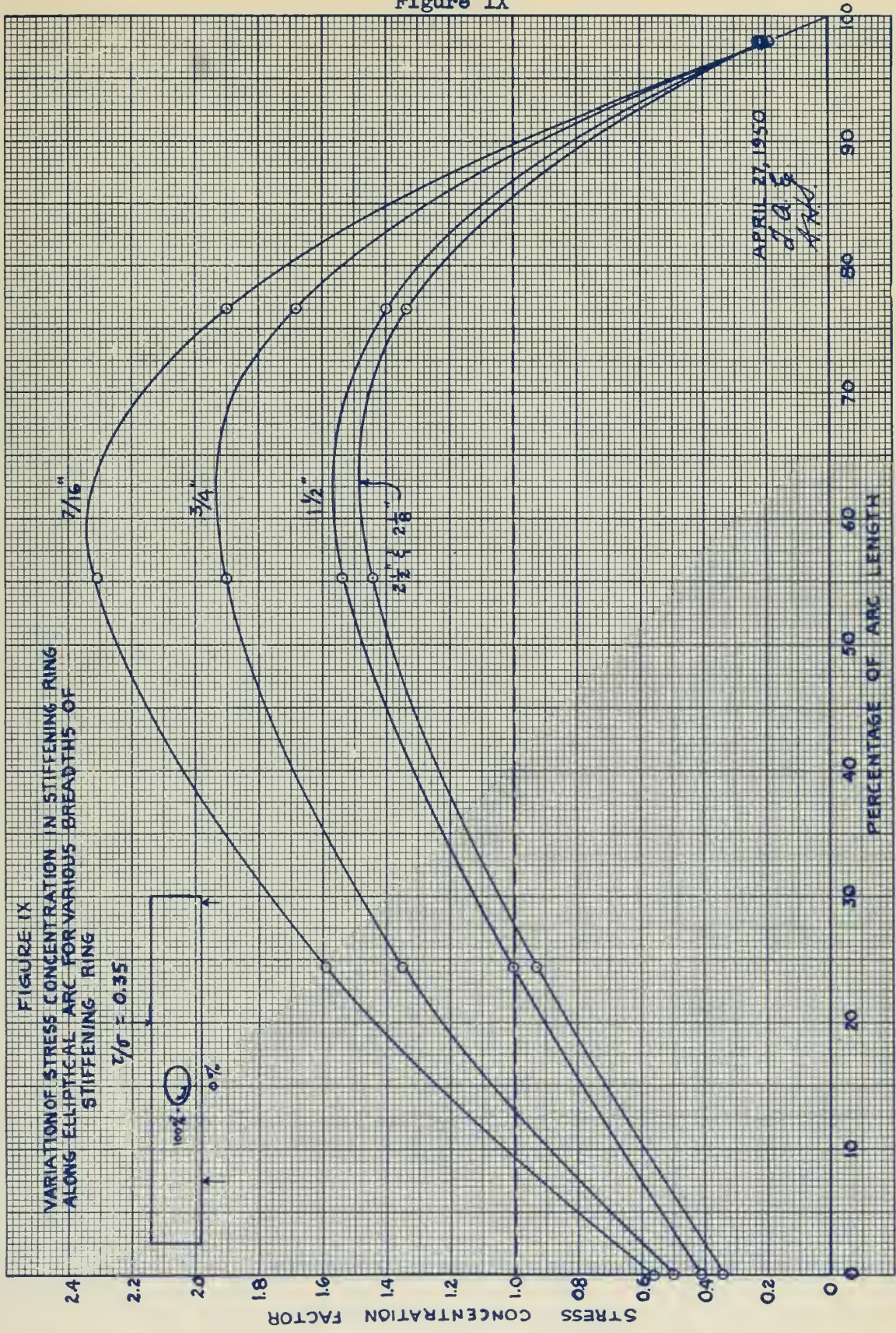






Figure X

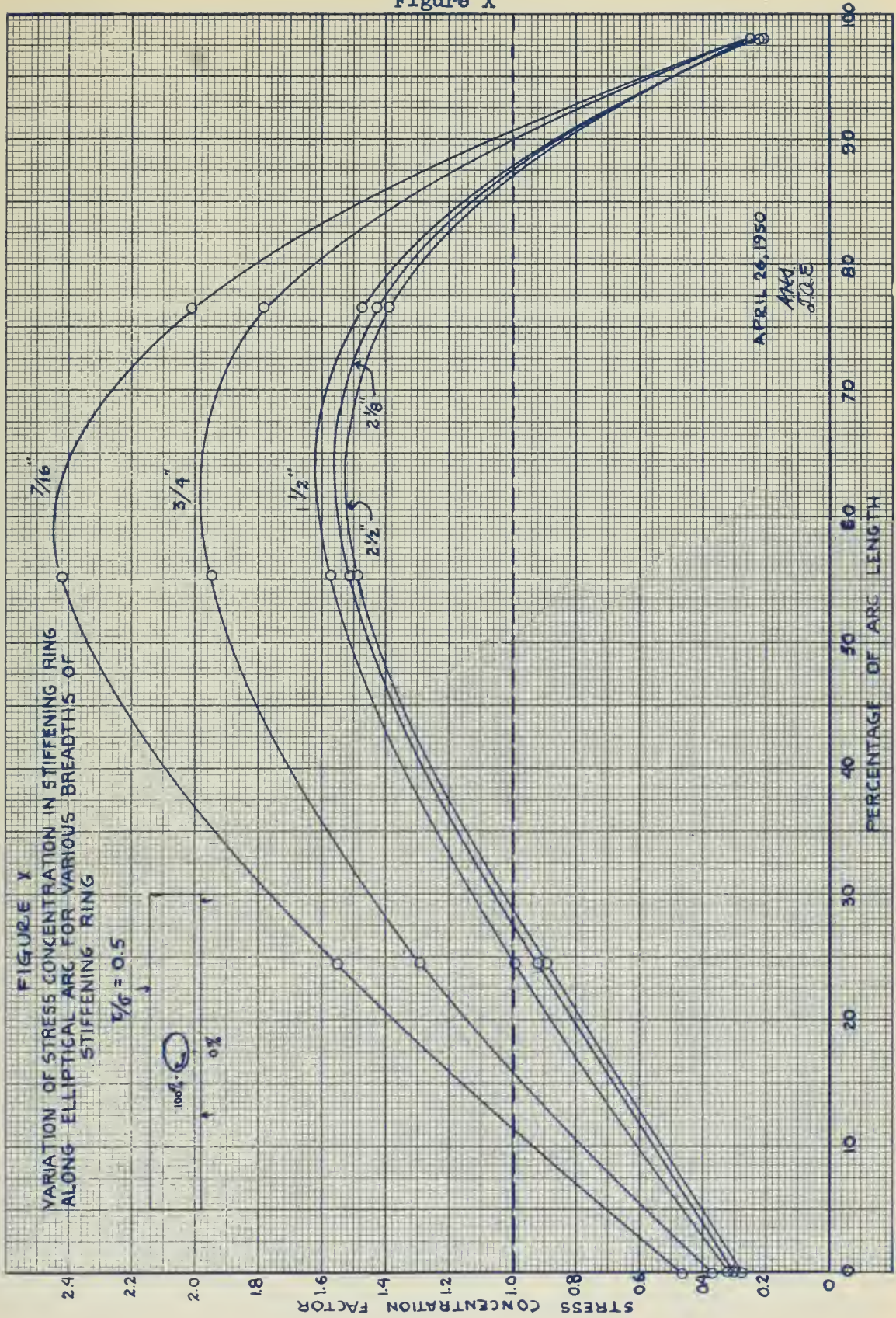
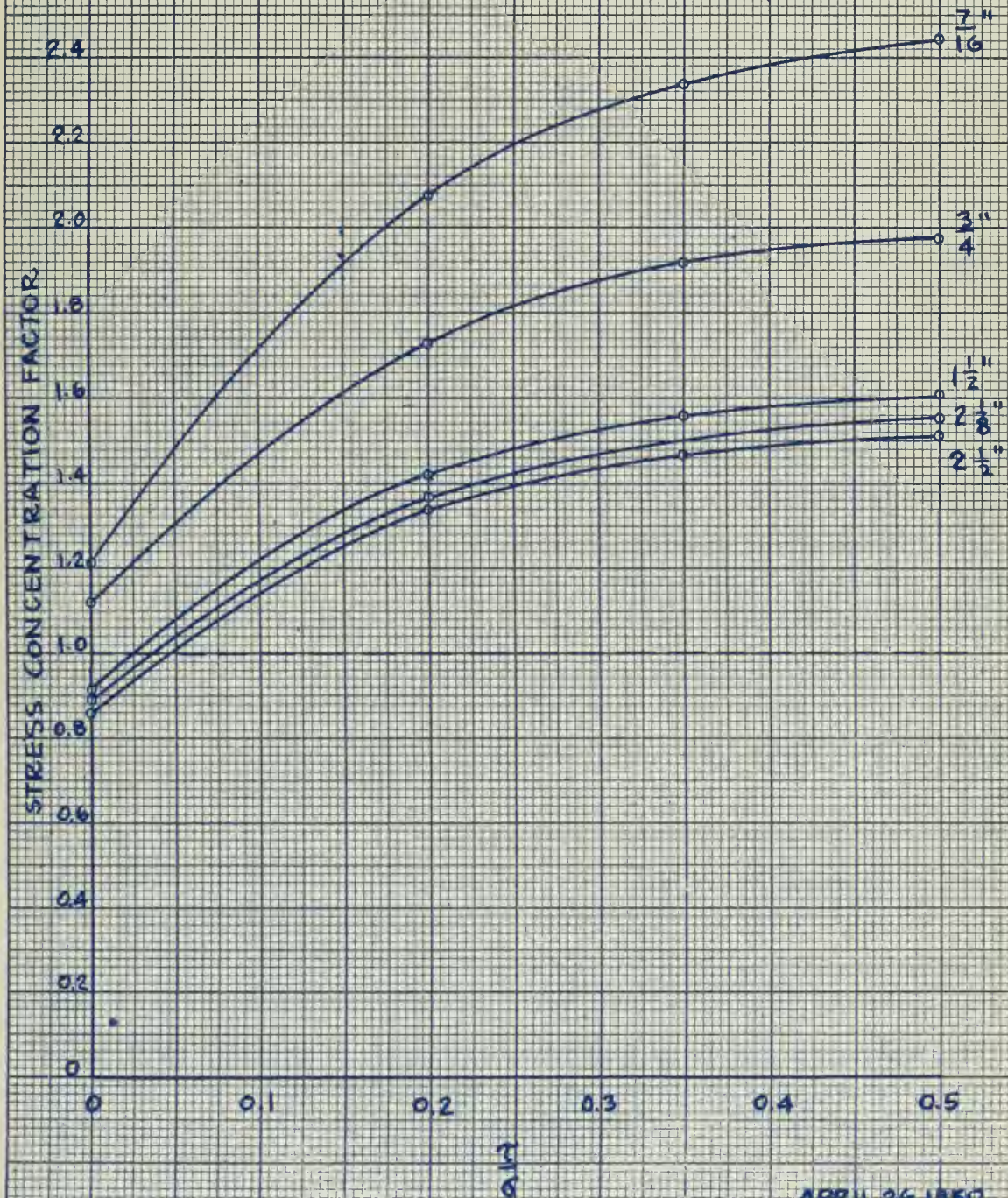






Figure XI

FIGURE XI  
MAXIMUM STRESS CONCENTRATION IN STIFFENING RING  
VS.  
RATIO OF SHEAR STRESS TO BENDING STRESS ( $\frac{\tau}{\sigma}$ )  
FOR  
VARIOUS BREADTHS OF STIFFENING RING



APRIL 26, 1950  
A.M. J.C.E.





Figure XII

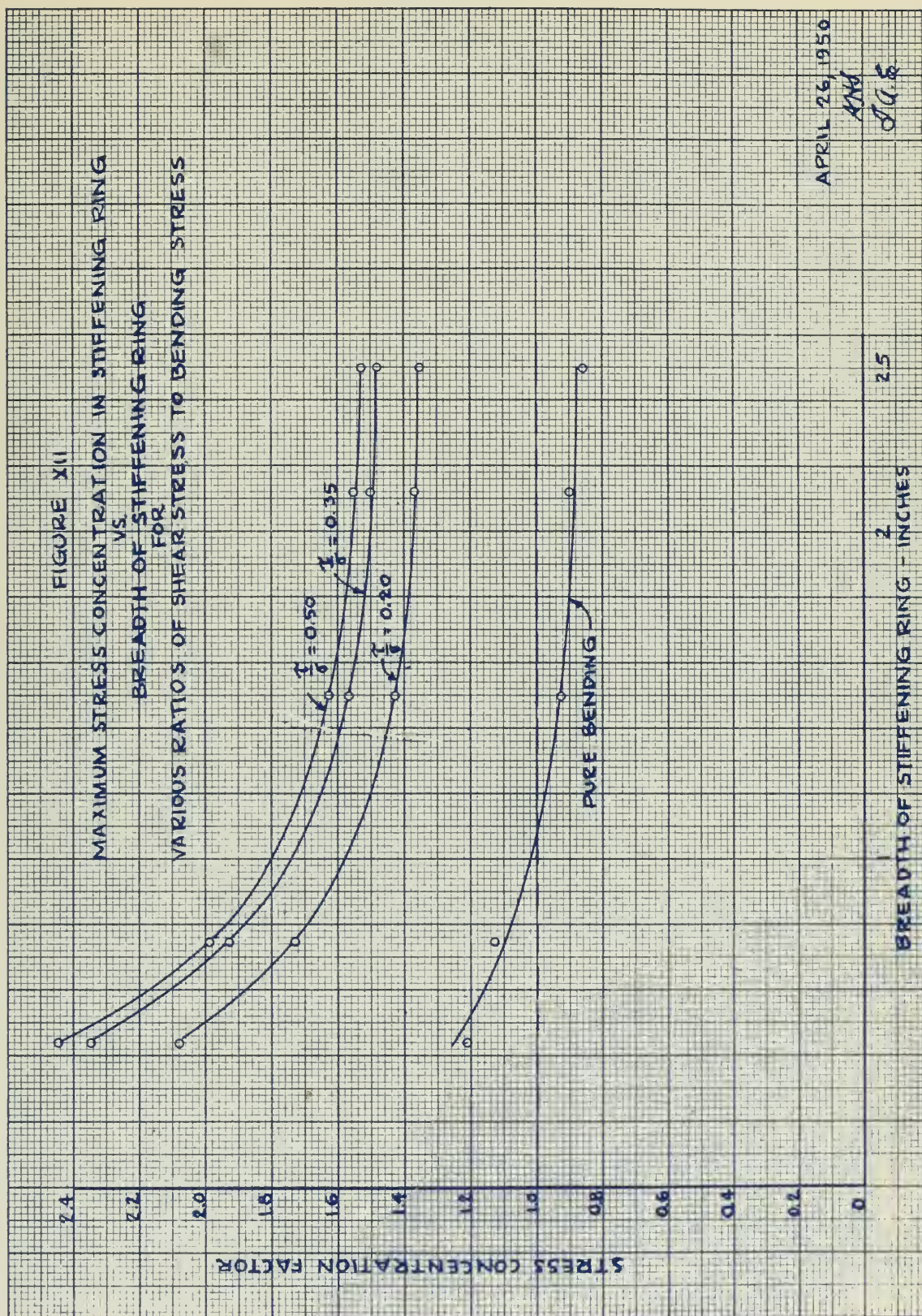






Figure XIII

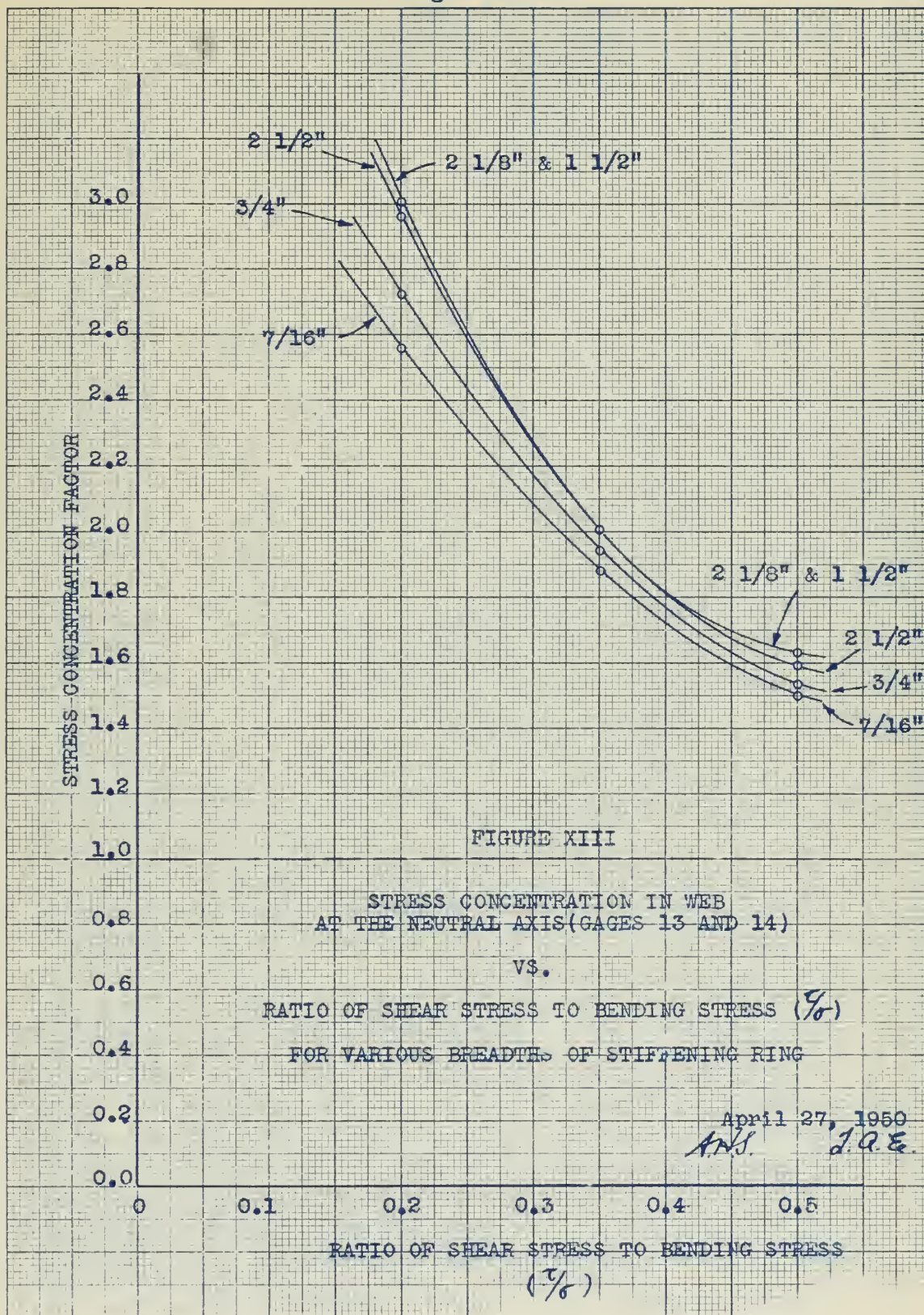






Figure XIV

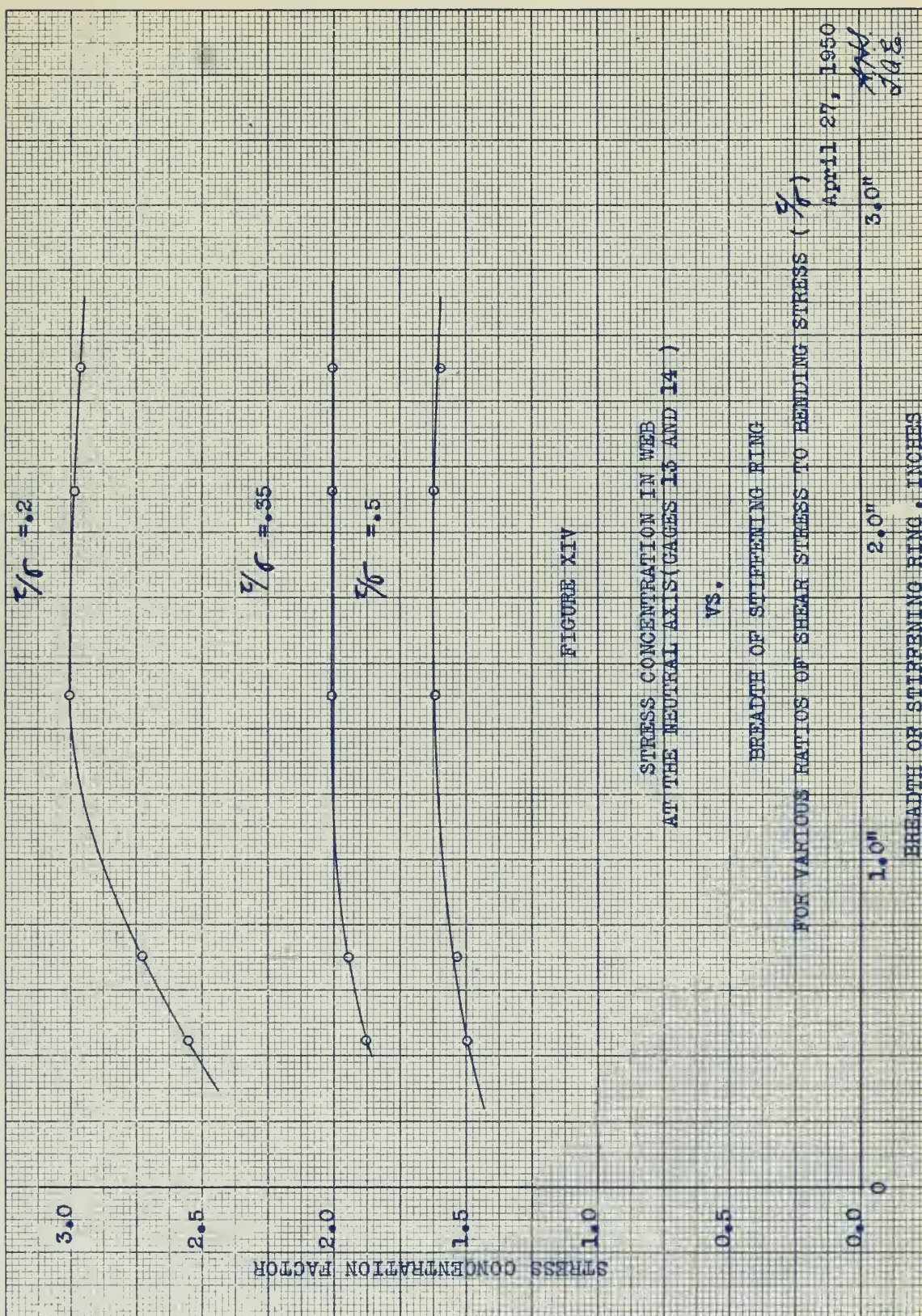






Figure XIV-A

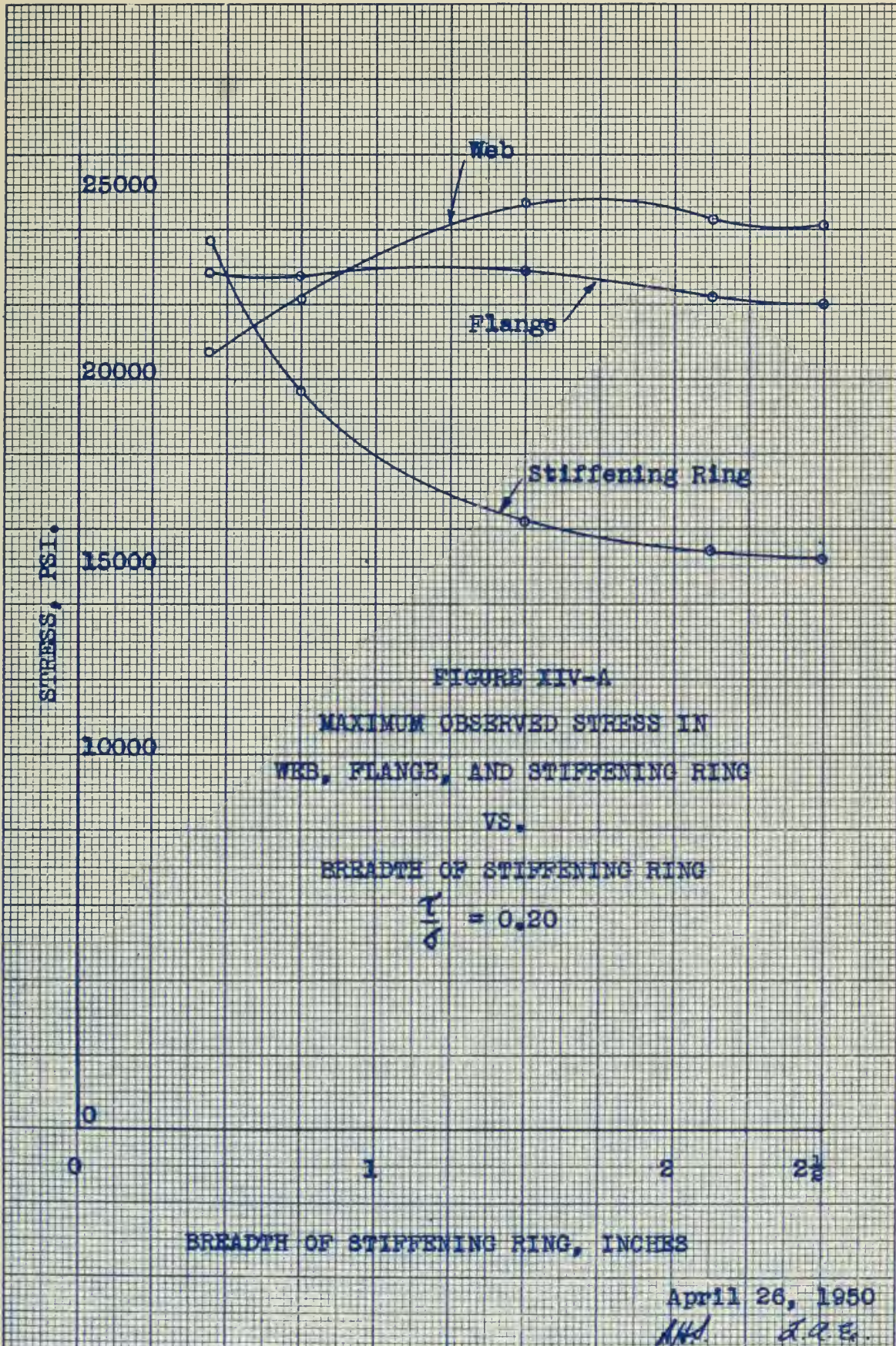






Figure XIV-B

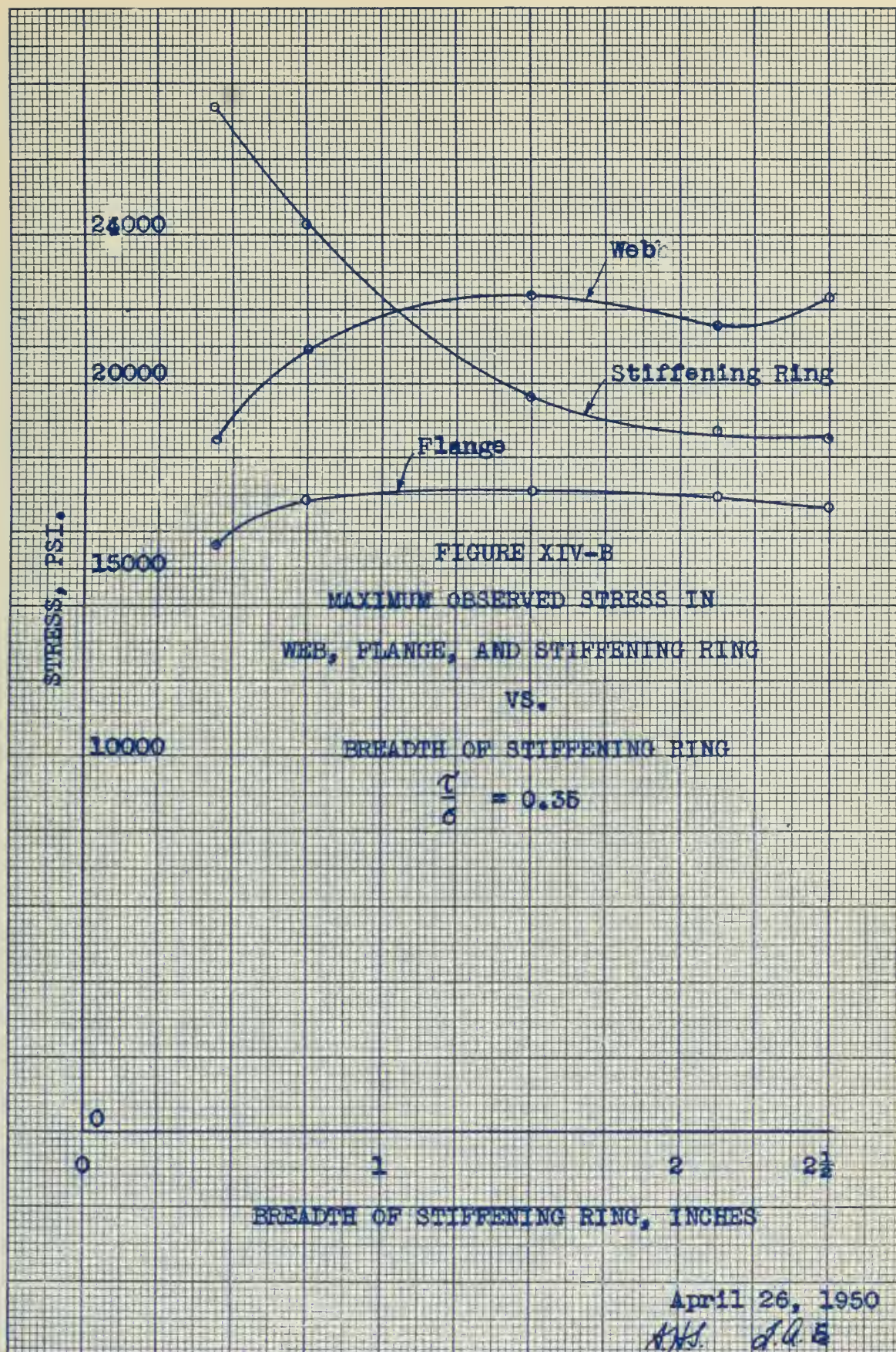






Figure XIV-C

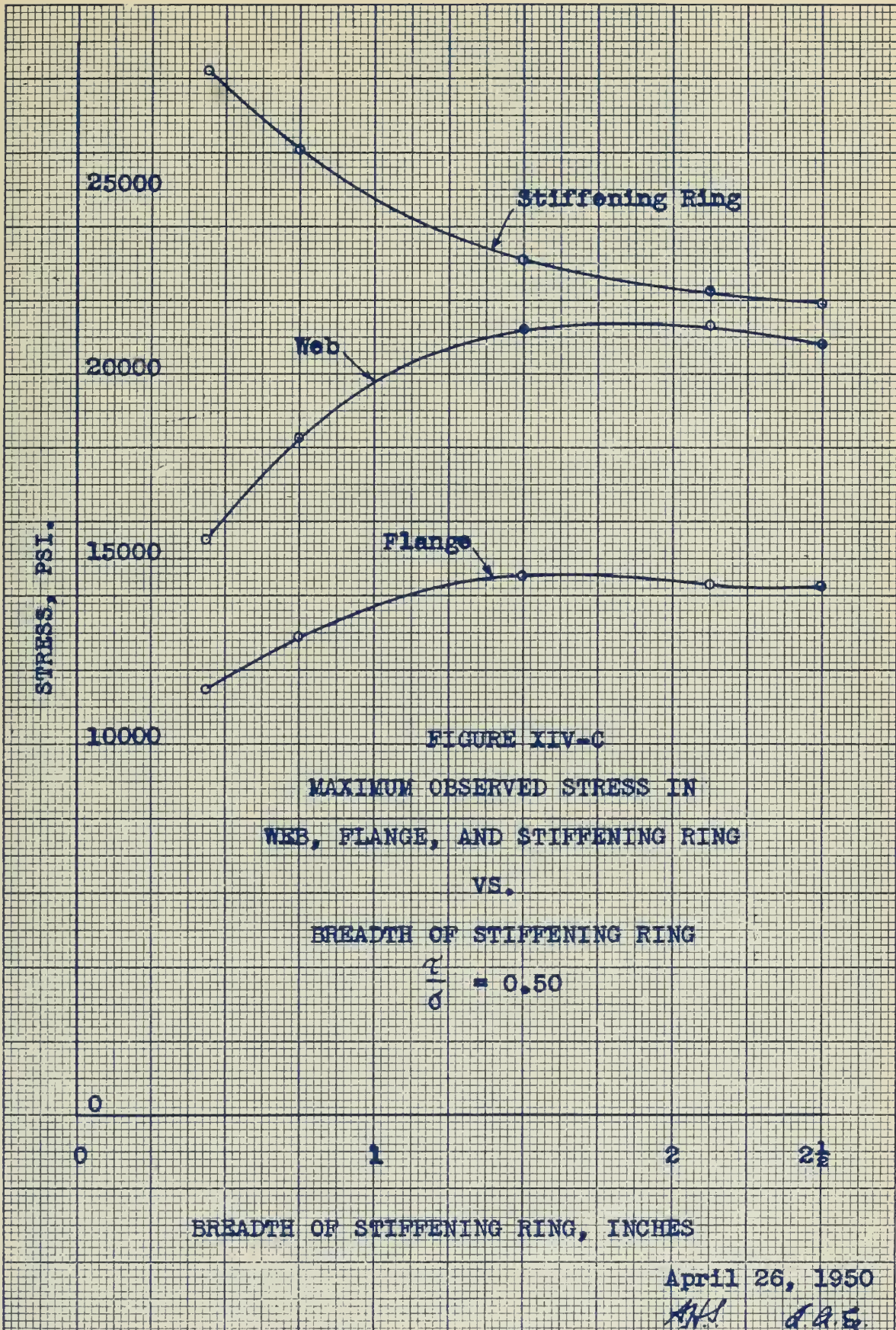
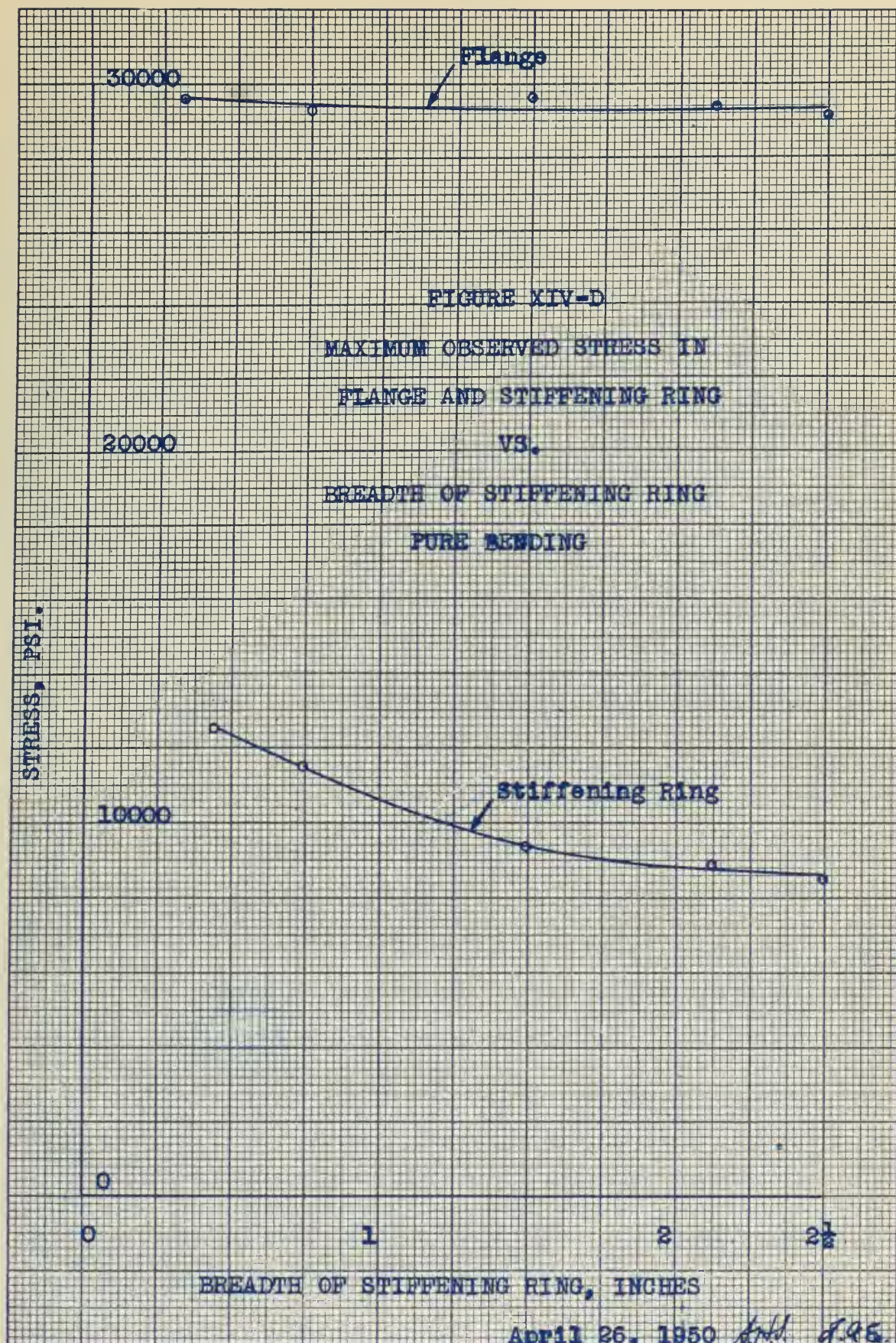






Figure XIV-D







### DISCUSSION OF RESULTS

From a study of Tables I-V it is found that the location of the highest stress in the vicinity of the opening varies with  $\tau/\sigma$  ratio and breadth of stiffening ring. Figures XIV-A, -B, -C, and -D show the magnitude of the maximum stress as derived from the gage readings for the most highly stressed points in the web, flanges and stiffening ring. The stresses for the web are taken from the readings of gages 13 and 14, those for the flanges from gages 20 and 21, and those for the stiffening ring from gage 17, except those for pure bending which are taken from gage 19, farthest from the neutral axis.

The web is the most highly stressed member at low  $\tau/\sigma$  ratios, but at  $\tau/\sigma = .50$  or greater, the location of the greatest stress is in the stiffening ring. The magnitude of this ring stress is high, and it is evident that yielding will occur in the ring before the web and flange stresses reach even a moderate value. If the breadth of the ring is less than four times the thickness of the web, the ring is the most highly stressed member for  $\tau/\sigma$  ratios above 0.35. When there is appreciable shear, it appears that there is always the likelihood of yielding in the ring, if its cross-sectional area is small. Hence for an unstiffened opening, the stresses will be high at the edge of the hole if there is appreciable shear.



Since the magnitude of the maximum web stress is always greater than the flange stress it is evident that yielding will take place in the web before it occurs at the extreme fibres, except when  $\tau/\sigma$  is less than 0.20 and the breadth of the ring less than  $3\frac{1}{2}$  times the web thickness (Figure XIV-A). Thus it is seen that the magnitude of the stress concentrations in the web and stiffening ring are greatly affected by the degree of shear.

#### Stiffening Ring

From the results obtained in pure bending, Figure VII, it is seen that the variation of stress concentration along the elliptical arc resembles closely the theoretical curve derived by Joseph and Brock (6) for an unreinforced ovaloid. Due to the fact that all reinforcement could not be removed without disturbing the gages installed, the stress concentration factors found for the elliptical hole are slightly less than the values given by the theoretical curve. Other differences between the observed and theoretical curves may be due to the difference in the shape of the opening. The experimental work of Karl, Heller, and Gerich (8), using a photoelastic model with an ovaloid opening, is also in good agreement with the theoretical curve. Both show that a reversal of stress takes place, as Figure VII indicates.

As shear is introduced, it is seen from Figures VIII, IX and X that the location of the maximum stress shifts toward the mid-length of the arc and is everywhere tensile. For  $\tau/\sigma = 0.20$ , the maximum value occurs



at about 55% of the arc length for each breadth, and shifts to about 60% for  $\tau/\sigma = 0.35$  and 0.50. It will be seen in Tables I-V that the concentration factors for the web gages, although smaller than those factors for the stiffening ring gages, show a slightly greater factor in each case for gages 7 and 8, situated nearly adjacent to the point for 60% of arc on the ring. Thus it is evident that the reinforcing ring is assuming a very large share of the load of the web in its vicinity.

Figures XI and XII are of most interest since they show the variation of maximum stress concentration factor with breadth of reinforcing ring and with loading condition respectively. With an increase of shear, the factor increases rather rapidly at first and then tends to approach a maximum value at a decreasing rate. At  $\tau/\sigma = 0.5$ , the factor for the 7/16" ring is 1.6 times as great as that for the 2½" ring. The factor remains below 1.60 for breadths greater than 1½", but at lesser breadths there is a rapid increase. This ring breadth of 1½" may be compared with the breadth of 1.43", which would replace the weight removed from the beam in cutting the elliptical opening. Hence if stresses are to be kept within the yield point, it is evident that the weight of stiffening required will slightly exceed the weight removed in the opening.

The influence of shear may be seen clearly in Figure XII, where the curve for pure bending lies well below those for the conditions with shear. Taking as an example the values of the factor for the case of the 1½"





stiffening ring, in pure bending the factor is 0.92, whereas at  $\tau/\sigma = 0.50$ , the factor is 1.61, or an increase of 75%. Thus it appears again that the degree of shear to which the section is subjected is of considerable importance.

The results obtained in pure bending are in agreement with those obtained by Ryan and Fischer (4) for the case of an unreinforced circular opening. They found that when the ratio of the diameter of the opening to the depth of the beam is less than  $\frac{1}{2}$ , the maximum stress occurs in the outer edge of the beam. In the present case, the ratio of the minor axis of the elliptical opening to the depth of the beam is 0.362, and it will be found from Table V, minimum reinforcement, for the case of pure bending, that the maximum stresses occur in the outer edge or flange gages (nos. 20-29).

#### Web

The high stress concentration factors found at the location of gages 13 and 14 are of interest, since the calculated stress for the intact beam is least for this point on the neutral axis. It is seen from Figure XIII that the maximum factor obtained, 3.04, occurs at  $\tau/\sigma = 0.20$  and is about the same for the  $2\frac{1}{2}$ ",  $2\frac{1}{8}$ " and  $1\frac{1}{2}$ " stiffening ring. An increase of the factor with decrease of shear and increase of stiffening ring is contrary to the behavior of the factor for the case of the stresses in the stiffening ring itself, previously mentioned.



Neuber (7) showed in his theoretical solution for stresses around a small elliptical opening in a bar subjected to bending and shear that there was a marked stress concentration due to shear just beyond the ends of the opening on the major (neutral) axis, which decreased to zero at the edge of the bar. His analysis was based on an elongated elliptical opening in a bar of relatively great width compared to the width of the opening. Using his formula for the maximum shear stress concentration

$$\frac{\tau_{max.}}{2bd} = 3 \frac{\left(\frac{t'}{\rho'} + 2\right)^{3/2} - \sqrt{\frac{t'}{\rho'}}}{\left(\sqrt{\frac{t'}{\rho'}} - 1\right)^2}$$

where  $t'$  = length of semi-major diameter

= radius of curvature of ellipse  
at end of semi-major diameter

$b$  =  $\frac{1}{2}$  depth of the bar

$d$  = thickness of the bar,

the maximum stress concentration factor is found to be 2.25 for the ellipse investigated. Since this calculated value is for an unreinforced opening and results show a decreasing value of stress concentration with reduction in stiffening ring width, the maximum stress concentration of 3.04 appears reasonable.



The stress concentration factor has been defined as the ratio of the observed stress to the theoretical stress of beam theory for the intact beam. The factor for gages 13 and 14 would therefore approach infinity in pure bending, since the theoretical stress is zero at the neutral axis. For the beam with the opening, the latter will of course not be the case, since stress will arise on the neutral axis because of the presence of the opening. This is the reason that the factor in Figures XIII and XIV approaches infinity as  $\tau/\sigma$  approaches zero.

A consideration of the variables involved in the expression for the calculation of the principal stress from observed strains will indicate which of these variables is at this point exerting the greatest influence on the derived stress. Consider, for example, the values given in Table I for  $\tau/\sigma = 0.20$  for gages 13 and 14. The strains  $\epsilon_x = 315$ ,  $\epsilon_y = -295$  are not significantly different in magnitude from the other web gages 1-12 and are nearly equal numerically but of opposite sign. The angle  $\theta$ , however, has the value 36.2 degrees. Secant  $2\theta$ , as used in the calculations, page , becomes secant  $72.4 = 3.307$ , which is three times as large as its value for the angles in the case of the other web gages. Furthermore, a reasonable maximum error of 0.5 degree in measuring this angle from the stresscoat diagram, Figure XVI, would result in a change in secant  $2\theta$  of 5.8%, which would be reflected in the value of the derived stress. Using equations (1), (2), and (3) given in the Appendix, page , in this case the stress concentration





factor would be changed by 4.4%, a figure which represents the maximum expected error for gages 13 and 14. It is evident, however, that this error is not sufficiently large to effect the validity of these results, which were confirmed by the results of the later tests with the supplementary "A" gages located at the former position of gages 13 and 14, as shown in Figure XXIV. The results obtained from gages 7A, 8A, and 9A in the Appendix, page 7, indicate that a stress concentration of the same order of magnitude occurs on the other side of the ellipse. At gages other than 13 and 14, the factors obtained for stresses in the web are comparatively low.

#### Flanges

The stress concentration factor on the outer surface of the flanges of the beam is invariable below unity, except for pure bending, where it reaches its maximum observed value of 1.03 for the  $\frac{7}{16}$ " ring in Table V. The factor decreases moderately with increase of  $\frac{I}{\sigma}$  ratio for constant ring breadth but does not show any appreciable change with variation of ring breadth at constant  $\frac{I}{\sigma}$ . This indicates that the maximum stress in the flanges is very little affected by a web discontinuity of the proportions tested, a result substantiated by previous investigators (4).

For conditions of loading other than pure bending, the factor shows its greatest value on the flange in way of the centerline of the opening (gages 20, 21). It decreases moderately with distance toward the left



support, but rises to another maximum (less than the first) in way of the left end of the ellipse (gages 28, 29), never attaining, however, values greater than unity.

For the case of pure bending, the situation is reversed. Here the minimum factor always occurs at the centerline of the hole, while all gages to the left show slightly higher values, never exceeding 1.03. A typical variation of the factor with distance from the vertical centerline of the ellipse is shown in Figure XLIII.

Figures XXII to XXIX inclusive show the relationship between load and gage reading for every gage for the tests of the  $1\frac{1}{2}$ " stiffening ring breadth. It is seen that this relationship is essentially linear after initial loading has removed any transverse twist in the beam due to errors of manufacture. After the stiffened opening was fabricated into the beam, it was discovered that the centerline of the web was offset  $1/8$ " from the centerline of the flanges. It is felt, however, that this fact does not appreciably affect the accuracy of the results.





## VI

### CONCLUSIONS

1. Stress concentrations do exist around a reinforced elliptical discontinuity in a beam subjected to complex bending.
2. If the thickness of the reinforcing ring is the same as that of the web, it appears that, from the relative magnitude of the stresses, yielding will take place in the web at the neutral axis before it occurs in the extreme fibres, if  $\tau/\sigma$  is greater than 0.20 and the breadth of the ring is less than  $3\frac{1}{2}$  times the thickness.
3. Yielding will occur first in the stiffening ring if  $\tau/\sigma$  is greater than 0.50, irrespective of the breadth of the ring. If the breadth is reduced to 4 times the thickness, yielding will occur first in the ring if  $\tau/\sigma$  is greater than 0.35.
4. The magnitude of the stress concentration in the reinforcement varies directly with the degree of shear and inversely with its cross-sectional area. The variation is not linear.
5. The magnitude of the principal stress concentration in the web of the beam at the neutral axis varies inversely with the degree of shear and directly with the cross-sectional area of the reinforcement. The variation is not linear.



6. The magnitude of the stress at the most extreme fibres of a wide flange I beam is very little affected by the presence of a centrally-located elliptical discontinuity, reinforced or unreinforced, whose depth is less than 0.36 times the depth of the beam.
7. In pure bending, the stress concentration factor nowhere greatly exceeds unity. In the stiffening ring, a reversal of stress occurs which disappears with the introduction of shear.
8. Stress concentration factors for the beam are not materially influenced by the width of reinforcing ring until the width is reduced below 7 times the thickness of the web.



## VII

### RECOMMENDATIONS

The authors recommend that

1. Further investigation be made of the stress distribution along the neutral axis of a beam in the vicinity of a reinforced discontinuity, the beam being loaded in complex bending.
2. A series of tests of ultimate strength be conducted for beams with various breadths of reinforcing ring. Since some local yielding due to high tensile concentrations is not harmful, the ultimate strength of the beam with the stiffened opening may actually exceed that of the intact beam.
3. For an opening constructed and reinforced similarly to the one tested, that the breadth of the reinforcing ring be not less than 7 times the thickness of the web.





VIII

APPENDIX



## APPENDIX A

### DETAILS OF PROCEDURE

#### A. Beam Selection and Fabrication

The decision having been made to test a beam with a reinforced elliptical discontinuity in complex bending, it was first necessary to decide on parameters and their variation. The parameters chosen were the variation in width of the flat bar stiffening ring and the variation of the ratio of nominal shear stress to bending stress in the intact beam at a section corresponding to the center of the major axis of the elliptical opening. The beam was simply supported, the load being applied at a point 21.5 inches from the center of the hole, and the variation in the ratio of shear stress to bending was effected by varying the distance of the support beyond the hole, as shown in the loading diagrams, Figure II.

The value of shear used in determining the ratio of nominal shear stress to bending stress, hereinafter referred to as  $\tau/\sigma$  was obtained by dividing the magnitude of the variable reaction "v" by the product of the depth of the beam "h" times the thickness of the web t, i. e.,

$$\tau = \frac{v}{h t} .$$

The bending stress used was that obtained at the surface of the beam flanges as calculated by the ordinary bending stress formula,

$$\sigma = \frac{m y}{I} .$$





It was desirable to have as large a variation in the ratio of shear stress to bending stress as possible and, with this in mind, a 12" x 6 $\frac{1}{2}$ " x 25# wide flange beam, eleven feet long was selected. This choice was also influenced by the size of the testing machine available as pertains to length and flange width of the specimen, and the desire to have a beam which could be handled easily. A depth of less than twelve inches did not appear feasible considering the amount of space required for strain gage installation.

The elliptically shaped hole was chosen since it permits a large access area for a given beam depth. The true elliptical shape was used in preference to two semi-circles joined by a straight section, since Obermeyer and Ballinger (5) found stress concentrations were set up at the points of tangency of the straight and semi-circular sections. The hole cut in the beam before the reinforcement was installed was 4.8 inches high by 7.2 inches long. This corresponds to a height of 0.4 of the beam depth and the major axis of the ellipse 1.5 times minor axis.

A high tensile steel beam was obtained from and the stiffening ring installed at the Boston Naval Shipyard. The stiffening ring was fabricated from a  $\frac{1}{4}$ " x 2 $\frac{1}{2}$ " mild steel flat bar and welded into the elliptical hole in two sections, with a v-weld at each end of the ellipse at the neutral axis as shown in Figure I. In addition to the installation of the stiffening ring, additional web stiffeners, cut from 10 pound plate,



were installed on either side of the web at a distance of 31 and 62 inches to the right of the hole center line as shown in Figure 2. These stiffeners were installed to reduce any tendency of the beam to twist and to carry the concentrated load into the beam web.

After all welding had been completed, the entire beam was placed in a furnace and stress relieved. The temperature in the furnace was raised from room temperature to approximately 1125°F at a steady rate over a period of 6 hours and 45 minutes. The furnace temperature was maintained at 1125°F for 1 hour, then the furnace was secured and the beam allowed to cool in the furnace for approximately 17 hours.

A standard flat plate tensile specimen in accordance with ASTM specifications was cut from the web of an excess portion of the beam to determine the modulus of elasticity. The modulus of elasticity was obtained as shown in Figure XL and Table XIII. A corresponding tensile specimen was made from a  $\frac{1}{4}$ " x  $2\frac{1}{2}$ " mild steel flat bar to determine the modulus of elasticity of the stiffening ring. The results of this tensile test are shown in Figure XLI and Table XIV. Both tensile tests were performed in the Baldwin Southwark 60,000 pound testing machine and the strains were measured by a pair of Huggenberger Tensometer gages mounted opposite each other to eliminate any bending effects.

#### B. Stress Coat Tests

In order to determine the lines of principal tensile strain around the access hole, it was necessary to run a series of stress coat tests. Stresscoat is sensitive to temperature and humidity which determine the



proper coating for any given atmospheric conditions. Psychrometer readings of wet-and-dry-bulb air temperatures were taken in the room where the specimen was coated and allowed to dry. Using these two temperature readings, the stresscoat calibration chart was entered and the specified coat selected. The area to be stresscoated was carefully power wire brushed and cleaned with a solvent (Methylisobutylketone). An aluminum-pigmented undercoating was sprayed over the surface in order to accentuate the stress coat cracks. After the aluminum coat had dried about 15 minutes, the stresscoat was sprayed on, using care to spray the coat on evenly and not too thick. Calibration strips were coated with stresscoat at the same time as the beam. The calibration strips, when loaded as a cantilever in the calibrating device, show the approximate sensitivity of the coat which has been applied to the specimen being tested. The nearer the strain cracks approach the point where the calibration strip is loaded, the more sensitive the coating, i. e., the less stress is required to crack it. After allowing the coating to dry 24 hours, the beam was tested for  $\tau/\sigma = 0.2$ , but the results were inconclusive. The stresscoat was crazed and the 55,000 pound load on the beam was insufficient to crack the stress coat excepting a small area in the web near the outer flanges. The calibration strips showed a strain sensitivity of 0.0006 corresponding to a stress of approximately 18,000 pounds per square inch.

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This stress coat was removed, the beam cleaned, and another coat applied, using the procedure described above. The technique for spraying the stress coat was better and a more uniform coat was obtained. The strain sensitivity for this coat was 0.00112, corresponding to about 33,000 psi required to crack the stress coat. This figure, coupled with the previous test, showed that the coat must be made more sensitive if any cracks were to be obtained. Due to the method of loading and the stress concentration directly beneath the load, the beam would yield at this section before it was possible to have sufficiently high stresses in way of the hole to crack the stresscoat possessing this low sensitivity. The beam was loaded to approximately 40,000 pounds and the area to which the stresscoat had been applied was suddenly cooled by a blast from a CO<sub>2</sub> fire extinguisher. A pattern of very fine cracks was obtained. These cracks were viewed most clearly by shining a flashlight on the surface at an angle in order to accentuate the discontinuities in the stress coat surface. To obtain a permanent record of these crack patterns, the contour of the cracks was first sketched on the beam in soft red pencil and then copied directly on tracing paper which was cut to fit on the beam web over the stress coated area. This tracing was oriented by centerlines scribed on the beam. An alternative method of recording the cracks is to use a red dye etch on the surface, wipe it off and photograph the strain pattern as outlined by the dye remaining in the cracks. However, the strain lines are so close together when obtained by suddenly chilling the beam that differentiation between the lines is rather poor.



The tracing procedure proved satisfactory and was used to record the strain cracks for  $\tau/\sigma = 0.2, 0.5$  and pure bending as shown in Figures XV thru XVII.

### C. Strain Gage Installation

The stress coat tests gave lines which were normal to the principal tensile strains. Because of the expense of the gages and limitation of time, only one quadrant of the ellipse was selected for detailed investigation. Figures XV and XVI showed that the greatest positive strains in the stiffening ring would occur in the lower left hand quadrant for the beam oriented as shown with the load to the right side of the hole; accordingly this quadrant was investigated.

The desire to get as near the stiffening ring as possible on the web, and to have the strains at a number of points, necessitated a relatively small strain gage, and precluded use of the rosette type. The gage best suiting these conditions as determined from Baldwin Bulletins (9-10) was the type A-3, SR-4 cupro nickel wire strain gage. These gages have a  $1/8$  inch gage length so the strains measured were quite well pin-pointed. To limit the number of gages to be installed in the web, only seven gages were applied to each side with the adjacent gages oriented normal to each other as shown in Figure I. In order to utilize this method, it was essential that none of the strain gages make an angle of  $45^\circ$  with any of the lines of principal strains, because in combining the measured strains in Mohr's circle using twice the angle between the axis of the gage and a line normal to the strain cracks at





the gage, an indeterminate condition would obtain if this angle were  $45^{\circ}$ . With this in mind, it was found by examining the stress coat patterns for all conditions of loading that the optimum gage orientation was  $20^{\circ}$  to the horizontal axis of the beam, with alternate gages normal to this orientation. Gages were placed in the same position and orientation on opposite sides of the web to eliminate the effect of any bending or twisting which might be introduced.

Five gages were placed inside the stiffening ring extending from the major axis to the minor axis of the elliptical arc chosen for investigation. These gages were placed in the vertical centerline plane of the web. Ten gages were placed on the top and bottom flanges of the beam, in a line coinciding with the centerline of the web and extending from the vertical centerline of the ellipse to a point approximately the same distance out as the gages installed on the neutral axis. It was desired to measure the strains in the flanges as well as the strains about the hole since Ryan and Fischer (4) found in studying beams with a central hole subjected to pure bending, that, if the ratio of the diameter of the hole to the depth of beam is less than  $\frac{1}{2}$ , the maximum stress occurs on the outer edge of the beam and is approximately equal to the stress in the beam without the hole. If the ratio is greater than  $\frac{1}{2}$  the edge of the hole becomes critical.

With the gage locations established, the area to receive gages was roughened with No. 000 sand paper and each gage location marked on the beam. Duco Household Cement was used to cement the strain gages in place.



The gages were covered with sponge rubber backed by a piece of 3-ply wood and held in place by clamps. The clamps were tightened just sufficiently to hold the sponge rubber in place. The clamps were removed after two days, but the gages were allowed to dry for a week before being used. Before soldering on leads of No. 20 copper wire, all the gages were checked by means of a volt-ohmmeter for continuity, grounds and specified resistance. All connections were soldered using rosin core solder.

#### D. Instrumentation

The instruments used to measure the strains were two Baldwin SR-4 Twenty-point switching units and a Baldwin Portable Strain Indicator, Model K. The switching unit combines a unique circuit which virtually eliminates all errors due to contact resistance. One dummy gage was used for all measurements and was mounted on the tensile test specimen taken from the beam web. During all tests this specimen was resting on the lower flange of the beam adjacent to the gages being tested, as can be seen in Figure VI. In order to utilize only one dummy gage with the switching units, all the dummy gage terminals on the end of the switching units were connected in series by a bare copper wire. The dummy gage terminals in the two switching units were then connected together. This wiring set up, as shown schematically in Figure XLII, permitted all gages to be switched into the Strain Indicator without shifting any connections.



#### E. Recording of Data

With the beam installed in the 100,000 pound Riehle testing machine as shown by the loading diagrams, Figure II and photographs Figures III through VI and all the instruments and gages properly connected, it was possible to start recording data. With the beam in position for a given ratio of shear stress to bending stress, or pure bending, as the case might be, an initial reading was taken for all strain gages using the strain indicator, which gives readings directly in micro-inches. The load was applied in four increments up to the maximum load and then decreased by the same increments down to zero. Strain readings were recorded for each increment of load, both increasing and decreasing. The strain for each load in each case is the difference between the value read at the load and the initial reading. Approximately  $1\frac{1}{2}$  hours were required to make a complete set of readings for a given  $\tau/\sigma$  ratio. Readings were taken both for increasing load and decreasing load in order to check the reliability of the gages. Figures XXVII through XXXIX show load vs. strain for all gages when the stiffening ring was  $1\frac{1}{2}$  inches wide.

#### F. Method of Reducing Width of Stiffening Ring

The stiffening ring width was reduced by clamping the beam, with the web horizontal, in a shaper then cutting transversely across the ring from one side to the other. This method proved very effective since the rate of cutting was slow enough that the heat generated was





insufficient to adversely affect the installed strain gages. However, it required extensive handling of the beam, since the shaper was located in the basement below the testing machine. In an attempt to eliminate unnecessary handling, the first reduction in stiffening ring width from  $2\frac{1}{2}$  to  $2\frac{1}{8}$  inches was accomplished by using a  $\frac{1}{4}$ " x 9 inch diameter cutting-off wheel driven by an air motor. The air motor was mounted in a jig which rested on the edges of the beam flanges so that the plane of the cutting off wheel was parallel to the beam web. This method proved unsatisfactory because the heat generated necessitated light cuts with intervals for cooling and required an excessive amount of time to perform the operation. As the width of the stiffening ring approached the thickness of the web there was danger of a chip damaging the gages installed on the web. The trim width of the A-8 gages installed on the stiffening ring was  $\frac{5}{16}$  of an inch while the web thickness was 0.24 inches. For these reasons the stiffening ring width was not reduced below  $\frac{7}{16}$  inch which allowed approximately 0.1 inch on each side of the web.

#### G. Stresscoat Test After Stiffening Ring Reduced to $\frac{7}{16}$ "

After completion of all strain gage measurements it was deemed desirable to make another stresscoat test to determine whether there was any appreciable change in the direction of the strain cracks after the stiffening ring had been reduced to  $\frac{7}{16}$  inch. This necessitated the removal of all the strain gages applied to the web. With the beam



stress coated as before it was tested for a value of  $\tau/\sigma = 0.5$ . The results of this test are shown in Figure XVIII, and also are shown superimposed for comparison on the original pattern for this ratio of  $\tau/\sigma$  in Figure XV.

#### H. Installation of Supplementary "A" Gages on the Neutral Axis

As a result of calculation based on the original data, it appeared that an extraordinary high stress concentration existed at the point where gages 13 and 14 were installed on the neutral axis. Since the strains normal to the orientation of gages 13 and 14 were extrapolated from gages 11 and 12 in the manner shown in Figures XIX through XXIII, it seemed advisable to obtain these normal strains as near to gages 13 and 14 as possible by direct measurement. Therefore, gages were reinstalled at the same location with the same orientation as gages 13 and 14, plus two more pairs of gages as close as possible on either side of the neutral axis and oriented normal to the orientation of gages 13 and 14 as shown in Figure XXIV. Use of rosette type gages was precluded by space considerations. Gages were also placed in a similar location at the opposite end of the elliptical opening, but only on one side of the beam, because no additional gages were available. The weld in the stiffening ring adjacent to gages 13 and 14 had a flaw which became apparent when the stiffening ring was reduced down to  $3/4$  inch width. It was thought that this flaw may have given rise to the stress concentration noted at gages 13 and 14 which are approximately  $3/4$  inch from the flaw. Since the weld was apparently satisfactory on the opposite side of the ellipse, the





installations of gages here would indicate whether the weld had a marked influence on the stress concentration factor. The location of these gages is shown in Figure XXIV. Following their installation, and, using the same procedure as before, the beam was tested again for  $\frac{P}{P_0} = 0.2, 0.35, 0.5$  and pure bending, and the data recorded as previously.

In order to obtain strains normal to the strains for gages 13 and 14 for all widths of stiffening ring an interpolation plot, Figure XXIV-A, was made from data obtained using the supplementary gages. Provided the material is not stressed beyond the yield point, the ratio of strains which are mutually perpendicular at a given point are constant for each loading condition. Therefore, the average strains for gages 1A, 2A, 5A and 6A were plotted vs. the average strains for gages 3A and 4A for each increment of load. Then, for any stiffening ring width, to obtain the strains normal to gages 13 and 14 which were located and oriented the same as the supplementary gages 3A and 4A, it is only necessary to enter Figure XXIV-A with the value of strain read by gages 13 and 14 and read off the corresponding normal strain. The method actually used in Table XII consisted of multiplying the strains measured by gages 13 and 14 by the tangent of the angle  $\alpha$  shown in Figure XXIV-A.



APPENDIX B

SUMMARY OF DATA AND CALCULATIONS



TABLE I

Observed Strains and Stress Concentration Factor for Each Gage Location  
Stiffening Ring Breadth =  $2\frac{1}{2}$ "

$\tau/c = 0.20$ , Load 37740 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	480	-208	10.8	505.9	-233.9	14490	15540	.93
3,4	435	-100	80.3	451.1	-116.1	13810	15190	.91
5,6	408	- 5	5.4	411.7	- 8.7	13540	14710	.92
7,8	405	15	88.5	405.2	14.8	13550	13840	.98
9,10	405	- 58	0.0	405.0	- 58.0	12840	12600	1.02
11,12	385	-255	83.6	393.2	-263.2	10480	10450	1.00
13,14	315	-295	36.2	1016.6	-998.6	24120	8123	2.96
15				62.0		1753	8215	.21
16				418.0		11820	9812	1.20
17				538.0		15210	11310	1.34
18				445.0		12580	12590	1.00
19				230.0		6504	13060	.50
20,21				728.0		22060	23090	.96
22,23				702.0		21270	22590	.94
24,25				676.0		20480	22130	.93
26,27				654.0		19820	21820	.90
28,29				660.0		20000	21340	.94
$\tau/c = 0.35$ , Load 40000 Lbs.								
1,2	464	-298	12.1	501.0	-335.0	13360	15600	.86
3,4	406	-136	77.7	433.0	-163.0	12760	15250	.84
5,6	387	0	14.2	413.5	- 26.5	13420	14890	.90
7,8	390	28	74.7	419.3	- 1.3	13858	14330	.97
9,10	400	- 50	1.5	400.3	- 50.3	12760	13560	.94
11,12	418	-308	84.2	425.7	-315.7	11050	12190	.91
13,14	420	-409	31.9	944.3	-933.3	22284	10700	2.08
15				85.0		2404	10800	.22
16				564.0		15950	11880	1.34
17				654.0		18490	12860	1.44
18				449.0		12700	13710	.93
19				156.0		4411	14040	.31
20,21				549.0		16630	17490	.95
22,23				486.0		14720	16840	.88
24,25				451.0		13660	16220	.84
26,27				429.0		13000	15800	.82
28,29				436.0		13210	15170	.87





TABLE I (cont'd)

$\nu/6 = 0.50$ , Load 44000 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	490	-375	13.5	543.4	-427.9	13870	16870	.82
3,4	420	-161	75.1	464.3	-205.3	13390	16570	.81
5,6	399	15	23.0	483.4	-69.4	15320	16230	.94
7,8	408	52	60.9	567.8	-107.8	17750	15820	1.12
9,10	430	-38	3.0	431.3	-39.3	13890	15230	.91
11,12	479	-359	84.7	486.3	-366.3	12570	14170	.89
13,14	505	-486	27.6	877.7	-858.7	20790	13070	1.59
15				119.0		3365	13160	.25
16				686.0		19400	13980	1.39
17				774.0		21890	14740	1.49
18				486.0		13740	15410	.89
19				128.0		3620	15710	.23
20,21				470.0		14240	14960	.95
22,23				380.0		11510	14160	.81
24,25				342.0		10360	13410	.77
26,27				322.0		9756	12890	.76
28,29				317.0		9605	12120	.79
Pure Bending, Load 44000 Lbs.								
1,2	364	13	21.4	427.7	-50.7	13660	14610	.94
3,4	342	2	59.0	534.1	-190.1	15850	14080	1.12
5,6	330	-11	28.1	466.0	-147.0	14000	13450	1.04
7,8	322	-22.5	62.6	448.5	-149.0	13410	12120	1.11
9,10	297	-33	24.4	382.5	-118.5	11516	9980	1.15
11,12	185	-47	78.0	196.0	-58.0	5928	5780	1.03
13,14	5	-52						
15				4.0		113	387	.29
16				8.0		226	4365	.05
17				118.0		3337	7475	.45
18				296.0		8371	9712	.86
19				301.0		8512	10420	.82
20,21				928.0		28120	28870	.97
22,23				926.0		28060	28870	.97
24,25								
26,27				958.0		29030	28870	1.01
28,29				961.0		29120	28870	1.01



TABLE II

Observed Strains and Stress Concentration Factor for Each Gage Location  
Stiffening Ring Breadth = 2-1/8"

$\frac{r}{C} = 0.20$ , Load 37740 Lbs.								
Gage No.	$\epsilon_x \times 10^6$	$\epsilon_y \times 10^6$	$\theta$ degrees	$\epsilon_1 \times 10^6$	$\epsilon_2 \times 10^6$	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	492	-230	10.8	519.3	-257.3	14710	15540	.95
3,4	445	-89	80.3	461.1	-105.1	14240	15190	.94
5,6	420	0	5.4	423.8	-3.8	13980	14710	.95
7,8	420	19	88.5	420.3	18.7	14080	13840	1.02
9,10	420	-55	0.0	420.0	-55.0	13360	12590	1.06
11,12	375	-245	83.6	382.9	-252.9	10240	10450	.98
13,14	317	-295	36.2	1022.9	-1000.9	24230	8123	2.98
15				60.0		1697	8215	.21
16				427.0		12070	9812	1.23
17				545.0		15410	11310	1.36
18				465.0		13150	12580	1.05
19				248.0		7013	13060	.54
20,21				734.0		22240	23090	.96
22,23				701.0		21240	22590	.94
24,25				663.0		20090	22140	.95
26,27				659.0		19970	21820	.91
28,29				663.0		20090	21342	.94
$\frac{r}{C} = 0.35$ , Load 40000 Lbs.								
1,2	475	-325	12.1	513.9	-363.9	13510	15600	.87
3,4	415	-127	77.7	432.0	-154.0	12810	15250	.84
5,6	398	3	14.2	425.0	-24.0	13830	14890	.93
7,8	403	33	74.7	432.9	3.1	14350	14330	1.00
9,10	412	-59	1.5	412.3	-59.3	13070	13570	.96
11,12	409	-358	84.2	468.2	-417.2	11480	12190	.94
13,14	405	-389	31.9	967.2	-891.2	21460	10700	2.01
15				85.0		2404	10800	.22
16				568.0		16060	11880	1.35
17				661.0		18690	12860	1.45
18				460.0		13010	13710	.95
19				163.0		4610	14040	.33
20,21				557.0		16880	17490	.96
22,23				495.0		15000	16840	.89
24,25				459.0		13910	16220	.86
26,27				442.0		13390	15800	.85
28,29				443.0		13420	15170	.88





TABLE II (cont'd)

$\nu/C = .50$ , Load 44000 Lbs.								
Gage No.	$\epsilon_x$ x106	$\epsilon_y$ x106	$\theta$ degrees	$\epsilon_1$ x106	$\epsilon_2$ x106	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	498	-450	13.5	556.0	-508.0	13520	16870	.80
3,4	426	-165	75.1	471.0	-210.0	13570	16570	.82
5,6	408	7	23.0	496.1	-81.1	15630	16230	.96
7,8	415	45	60.9	581.1	-121.1	18060	15820	1.14
9,10	433	-36	3.0	434.3	-37.3	14010	15230	.92
11,12	482	-405	84.7	479.5	-402.5	10330	14170	.73
13,14	518	-498	27.6	900.1	-880.1	21330	13070	1.63
15				101.0		2856	13160	.22
16				705.0		19940	13980	1.43
17				786.0		22230	14740	1.51
18				501.0		14170	15410	.92
19				138.0		3903	15720	.25
20,21				473.0		14330	14765	.96
22,23				393.0		11190	14170	.81
24,25				347.0		10510	13420	.78
26,27				325.0		9847	12900	.76
28,29				326.0		9878	12130	.81
Pure Bending, Load 44000 Lbs.								
1,2	384	18	21.4	450.4	-48.4	14440	14610	.99
3,4	368	2	59.0	574.8	-204.8	17050	14080	1.21
5,6	345	-15	28.1	488.6	-158.6	14640	13450	1.09
7,8	329	-24	62.6	458.7	-153.7	13700	12120	1.13
9,10	313	-30	24.4	401.9	-118.9	12150	9980	1.22
11,12	193	-35	78.0	203.8	-45.8	6302	5780	1.09
13,14	11	-33						
15				5.0		141	387	.36
16				1.0		28	4365	.06
17				132.0		3733	7475	.50
18				307.0		8682	9712	.89
19				317.0		8965	10420	.86
20,21				940.0		28480	28870	.99
22,23				954.0		28900	28870	1.00
24,25				972.0		29450	28870	1.02
26,27				965.0		29240	28870	1.01
28,29				972.0		29450	28870	1.02



TABLE III

Observed Strains and Stress Concentration Factor for Each Gage Location  
Stiffening Ring Breadth =  $1\frac{1}{2}$ "

$\eta/\delta = 0.20$ , Load 37987 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	506	-186	10.8	532.1	-212.1	15570	15540	1.00
3,4	475	-100	80.3	491.3	-117.3	15130	15190	1.00
5,6	447	-23	5.4	451.2	-27.2	14665	14710	.99
7,8	440	12	88.5	440.3	11.7	14450	13840	1.04
9,10	434	-48	0.0	434.0	-48.0	13900	12590	1.10
11,12	374	-241	83.6	380.8	-248.8	10210	10450	.98
13,14	323	-301	36.2	1042.7	-1020.7	24700	8123	3.04
15				53.0		1500	8276	.18
16				445.0		12580	9880	1.27
17				571.0		16150	11390	1.42
18				506.0		14310	12670	1.13
19				264.0		7460	13150	.57
20,21				755.0		22880	23250	.98
22,23				715.0		21660	22750	.95
24,25				694.0		21030	22290	.92
26,27				674.0		20420	21970	.93
28,29				678.0		20540	21490	.95
$\eta/\delta = 0.35$ , Load 39945 Lbs.								
1,2	481	-270	12.1	516.4	-306.4	14140	15600	.91
3,4	423	-137	77.7	450.9	-164.9	13330	15250	.87
5,6	419	-23	14.2	449.2	-30.2	14570	14890	.98
7,8	421	27	74.7	452.9	-4.9	14940	14330	1.04
9,10	422	-38	1.5	422.3	-38.3	13600	13570	1.00
11,12	423	-302	84.2	431.7	-309.7	11310	12190	.93
13,14	423	-407	31.9	948.0	932.0	22420	10700	2.09
15				73.0		2064	10800	.19
16				590.0		16680	11880	1.40
17				694.0		19630	12860	1.53
18				508.0		14370	13710	1.05
19				185.0		5230	14040	.37
20,21				564.0		17090	17500	.98
22,23				502.0		15210	16841	.90
24,25				463.0		14030	16225	.86
26,27				444.0		13450	15800	.85
28,29				448.0		13570	15170	.89





TABLE III (cont'd)

$\tau/\sigma = 0.50$ , Load 43950 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	496	-355	13.5	547.0	-407.0	14190	16870	.84
3,4	462	-170	75.1	510.1	-218.1	14780	16570	.89
5,6	429	-18	23.0	544.0	-116.0	16880	16230	1.04
7,8	427	41	60.9	600.2	-132.2	18580	15820	1.17
9,10	443	-38	3.0	444.3	-39.3	14320	15230	.94
11,12	490	-357	84.7	496.4	-364.4	12920	14170	.91
13,14	515	-495	27.6	894.9	-874.9	21210	13070	1.62
15				98.0		2770	13160	.21
16				727.0		20560	13980	1.47
17				816.0		23080	14740	1.57
18				540.0		15270	15410	.99
19				140.0		3960	15720	.25
20,21				478.0		14480	14965	.97
22,23				398.0		12060	14170	.85
24,25				346.0		10480	13420	.78
26,27				328.0		9938	12900	.77
28,29				327.0		9908	12130	.82
Pure Bending, Load 43980 Lbs.								
1,2	374	26	21.4	437.1	-37.1	15300	14610	1.04
3,4	360	-4	59.0	565.7	-209.7	16700	14080	1.19
5,6	341	-25	28.1	487.0	-171.0	14470	13450	1.07
7,8	320	-37	62.0	450.8	-166.8	13310	12120	1.10
9,10	292	-36	24.4	377.0	-121.0	11310	9980	1.14
11,12	163	-35	78.0	172.4	-9.4	5614	5780	.97
13,14	-8	-35						
15				5.0		141	387	.36
16				-16.0		-452	4365	-.10
17				107.0		3026	7475	.40
18				312.0		8823	9712	.91
19				332.0		9389	10420	.89
20,21				944.0		28600	28870	.99
22,23				960.0		29090	28870	1.01
24,25				977.0		29600	28870	1.02
26,27				972.0		29450	28870	1.02
28,29				976.0		29570	28870	1.02





TABLE IV

Observed Strains and Stress Concentration Factor for Each Gage Location  
Stiffening Ring Breadth =  $3/4"$

$\tau/c = 0.20$ , Load 38005 Lbs.								
Gage No.	$\epsilon_x$ x106	$\epsilon_y$ x106	$\theta$ degrees	$\epsilon_1$ x106	$\epsilon_2$ x106	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	517	-214	10.8	543.5	-392.5	14210	15540	.91
3,4	512	-125	80.3	531.1	-143.1	16200	15190	1.08
5,6	507	-43	5.4	511.9	-47.9	16474	14710	1.12
7,8	497	-21	88.5	497.4	-21.4	16250	13840	1.17
9,10	473	-82	0.0	468.0	-87.0	14650	12590	1.16
11,12	395	-232	83.6	402.0	-240.0	10980	10450	1.05
13,14	290	-269	36.2	934.8	-913.8	22160	8123	2.73
15				58.0		1640	8276	.20
16				523.0		14790	9880	1.50
17				696.0		19680	11390	1.73
18				650.0		18380	12670	1.45
19				329.0		9300	13150	.71
20,21				751.0		22750	23250	.98
22,23				701.0		21240	22750	.94
24,25				676.0		20480	22290	.92
26,27				663.0		20090	21970	.91
28,29				664.0		20120	21490	.93
$\tau/c = 0.35$ , Load 39955 Lbs.								
1,2	487	-270	12.1	522.7	-306.7	14350	15600	.92
3,4	492	-148	77.7	523.9	-179.9	15600	15250	1.02
5,6	491	-35	14.2	527.0	-71.0	16752	14890	1.12
7,8	490	-4	74.7	530.0	-44.0	17110	14330	1.19
9,10	485	-70	1.5	484.4	-70.4	15350	13570	1.13
11,12	445	-290	84.2	451.8	-297.8	12088	12190	.98
13,14	394	-379	31.9	882.9	-867.9	20880	10700	1.95
15				87.0		2460	10800	.23
16				710.0		20080	11880	1.69
17				858.0		24260	12860	1.89
18				658.0		18600	13710	1.36
19				227.0		6420	14040	.46
20,21				555.0		16820	17500	.96
22,23				476.0		14420	16841	.86
24,25				443.0		13420	16225	.83
26,27				429.0		13000	15800	.82
28,29				430.0		13030	15170	.86



TABLE IV (cont'd)

$\tau/\sigma = 0.50$ , Load 39995 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	498	-322	13.5	548.0	-373.0	14560	15320	.95
3,4	472	-164	75.1	520.0	-212.0	15150	15050	1.01
5,6	463	- 22	23.0	568.0	-128.0	17560	14740	1.19
7,8	469	9	60.9	675.0	-197.0	20440	14365	1.42
9,10	472	- 54	3.0	473.4	- 55.4	15110	13830	1.09
11,12	462	-308	84.7	546.0	-238.0	15780	12870	1.23
13,14	443	-426	27.6	769.8	-752.8	18250	11870	1.54
15				108.0		3054	11970	.25
16				801.0		22650	12710	1.78
17				922.0		26070	13400	1.95
18				641.0		18130	14000	1.29
19				158.0		4468	14290	.31
20,21				426.0		12900	13600	.95
22,23				346.0		10480	12880	.81
24,25				294.0		8910	12190	.73
26,27				278.0		8423	11720	.72
28,29				279.0		8454	11020	.76
Pure Bending, Load 43980 Lbs.								
1,2	408	- 10	21.4	483.8	- 85.8	15180	14610	1.04
3,4	391	- 31	59.0	629.4	-269.4	18240	14080	1.30
5,6	362	- 50	28.1	526.3	-214.3	15360	13450	1.14
7,8	330	- 55	62.0	470.1	-196.1	13670	12120	1.13
9,10	279	- 56	24.4	365.5	-141.5	10730	9980	1.08
11,12	130	- 36	78.0	137.8	- 43.8	4140	5780	.71
13,14	-28	- 19						
15				- 2.0		- 56	387	-.14
16				-41.0		-1160	4365	-.27
17				107.0		3026	7475	.40
18				383.0		10831	9712	1.12
19				409.0		11560	10420	1.11
20,21				931.0		28210	28870	.98
22,23				950.0		28780	28870	.99
24,25				964.0		29210	28870	1.01
26,27				965.0		29240	28870	1.01
28,29				966.0		29270	28870	1.01





TABLE V

Observed Strains and Stress Concentration Factor for Each Gage Location  
Stiffening Ring Breadth = 7/16"

$t/c = 0.20$ , Load 37950 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	525	-220	10.8	553.1	-248.1	15920	15540	1.02
3,4	550	-138	80.3	570.7	-158.7	17360	15190	1.14
5,6	565	-62	5.4	570.6	-67.6	18230	14710	1.24
7,8	558	-34	88.5	558.4	-34.4	18140	13840	1.31
9,10	524	-40	0.0	524.0	-40.0	16950	12590	1.35
11,12	402	-162	83.6	409.2	-169.2	11910	10450	1.14
13,14	272	-252	36.2	876.4	-856.4	20770	8123	2.56
15				52.0		1470	8276	.18
16				577.0		16330	9880	1.65
17				837.0		23700	11390	2.08
18				702.0		19900	12670	1.57
19				347.0		9820	13150	.75
20,21				753.0		22820	23250	.98
22,23				700.0		21210	22750	.93
24,25				670.0		20300	22290	.91
26,27				657.0		19910	21970	.91
28,29				660.0		20000	21490	.93
$t/c = 0.35$ , Load 36885 Lbs.								
1,2	451	-279	12.1	321.9	-149.9	9210	14390	.64
3,4	487	-145	77.7	518.5	-176.5	15460	14060	1.10
5,6	520	-22	14.2	557.1	-59.1	17860	13730	1.30
7,8	528	26	74.7	568.6	-14.6	18670	13210	1.41
9,10	517	16	1.5	517.4	15.6	17260	12510	1.38
11,12	440	-184	84.2	446.6	-190.6	12940	11240	1.15
13,14	350	-337	31.9	784.5	-771.5	18550	9866	1.88
15				74.0		2092	9963	.21
16				737.0		20840	10950	1.90
17				970.0		27431	11860	2.32
18				710.0		20080	12641	1.59
19				235.0		6645	12950	.51
20,21				520.0		15760	16130	.98
22,23				450.0		13630	15530	.88
24,25				407.0		12330	14960	.83
26,27				390.0		11820	14670	.81
28,29				395.0		11970	13990	.85



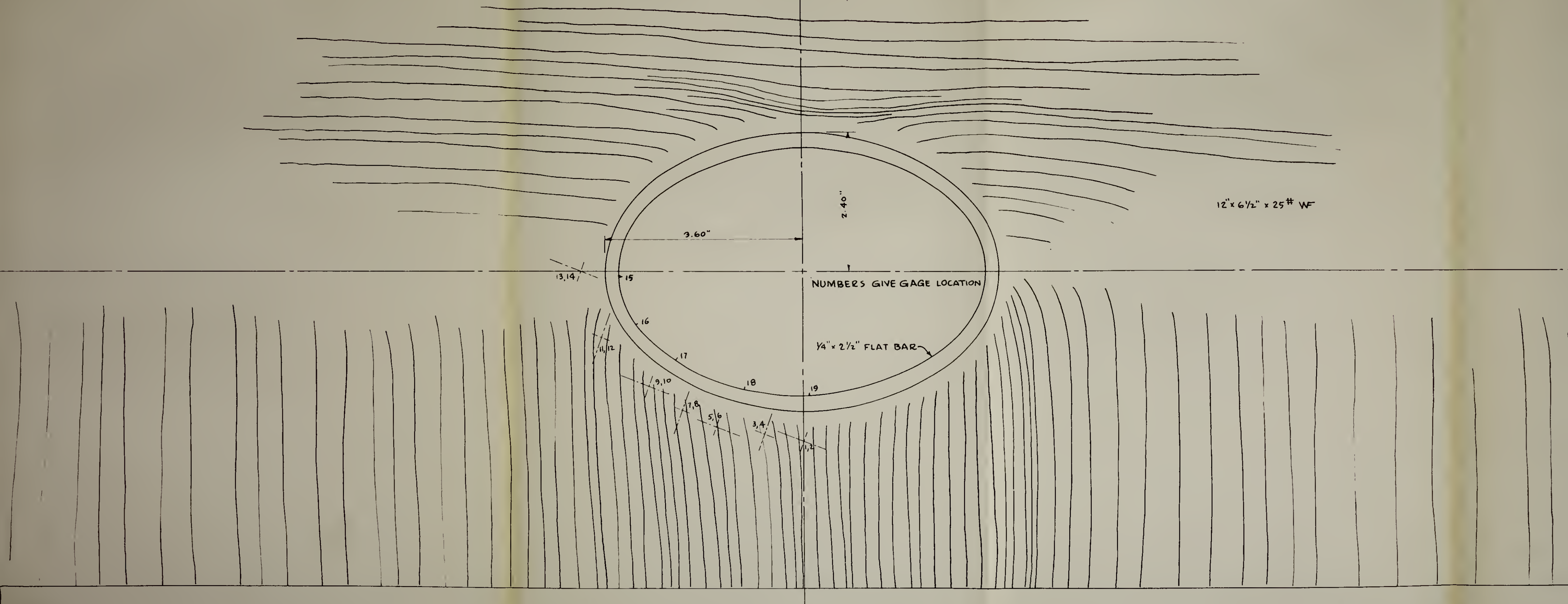
TABLE V (cont'd)

$\tau/\sigma = 0.50$ , Load 34750 Lbs.								
Gage No.	$\epsilon_x$ x10 <sup>6</sup>	$\epsilon_y$ x10 <sup>6</sup>	$\theta$ degrees	$\epsilon_1$ x10 <sup>6</sup>	$\epsilon_2$ x10 <sup>6</sup>	$\sigma_1$ psi	$\sigma_1$ (calc) psi	Stress conc. factor
1,2	395	-281	13.5	436.3	-322.3	11340	13320	.86
3,4	437	-142	75.1	481.1	-186.1	14130	13090	1.08
5,6	477	-11	23.0	584.3	-118.3	18190	12820	1.42
7,8	492	42	60.9	694.0	-160.0	21424	12490	1.72
9,10	495	43	3.0	496.2	41.8	16820	12030	1.40
11,12	440	-160	84.7	445.2	-165.2	13140	11190	1.08
13,14	376	-362	27.6	653.6	-639.6	15490	10320	1.50
15				91.0		2573	10390	.25
16				793.0		22420	11040	2.03
17				998.0		28220	11640	2.42
18				667.0		18860	12170	1.55
19				165.0		4660	12410	.37
20,21				379.0		11480	11820	.97
22,23				301.0		9120	11190	.82
24,25				254.0		7696	10590	.73
26,27				237.0		7181	10186	.71
28,29				241.0		7300	9580	.76
Pure Bending, Load 43925 Lbs.								
1,2	445	-35	21.4	532.1	-122.1	16430	14610	1.12
3,4	336	-45	59.0	551.3	-260.3	15740	14080	1.12
5,6	294	-50	28.1	431.2	-187.2	12500	13450	.93
7,8	290	-50	62.0	414.9	-174.9	12050	12120	.99
9,10	281	-46	24.4	365.7	-130.7	10840	9980	1.09
11,12	178	-22	78.0	187.5	-31.5	5901	5780	1.02
13,14								
15				0.0		0	387	.00
16				-79.0		-2230	4365	-.51
17				112.0		3170	7475	.42
18				412.0		11650	9712	1.20
19				442.0		12500	10420	1.20
20,21				946.0		28660	28870	.99
22,23				960.0		29080	28870	1.01
24,25				977.0		29600	28870	1.03
26,27				976.0		29570	28870	1.02
28,29				974.0		29510	28870	1.02





FIGURE XV



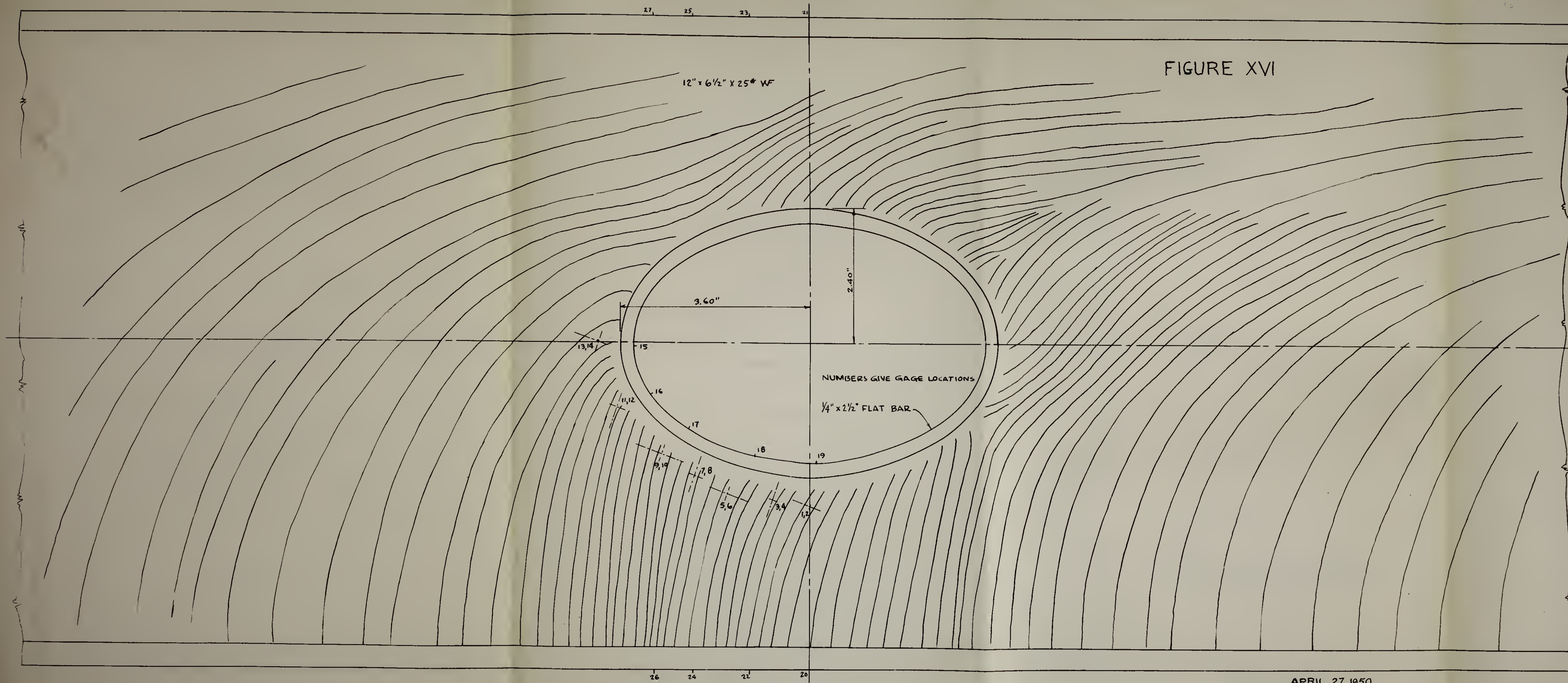
STRESSCOAT CRACKS  
PURE BENDING

APRIL 27, 1950  
L.H. J.G.





FIGURE XVI



STRESSCOAT CRACKS

$\tau/\sigma = .2$

APRIL 27, 1950  
A.H.S. J.A.B.





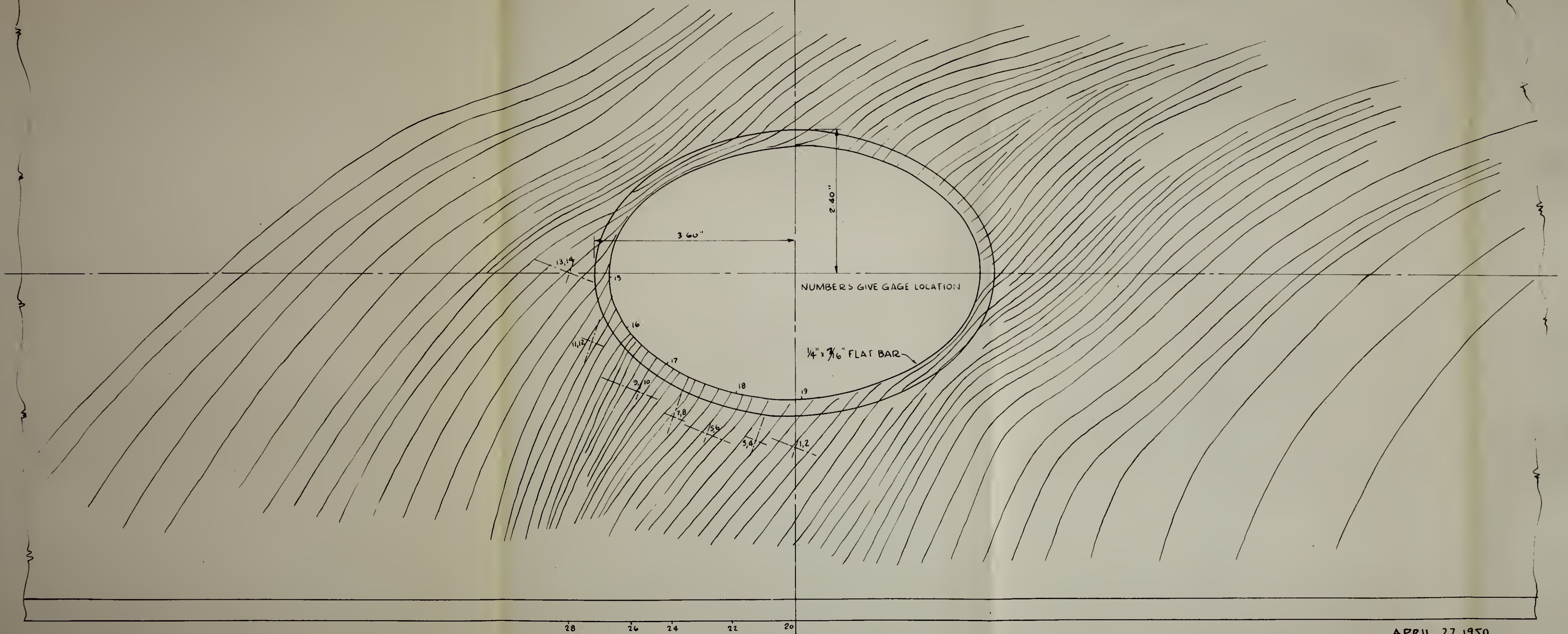






29 27 25 23 21  
12" x 6 1/2" x 25# WF

FIGURE XVIII



STRESSCOAT CRACKS

$\tau/\sigma = .5$

APRIL 27, 1950  
A.W.S. JUE





Figure XIX

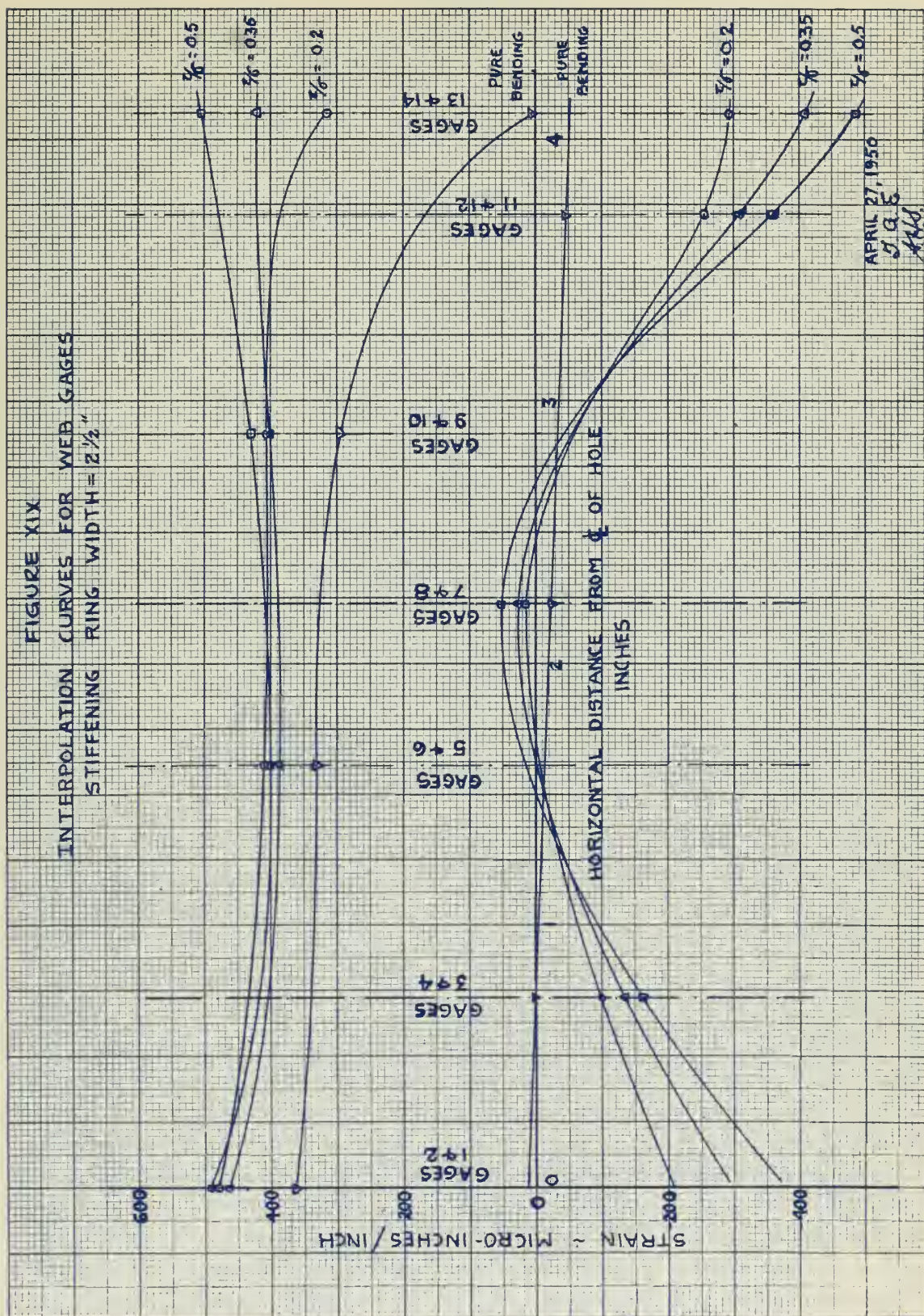






Figure XX

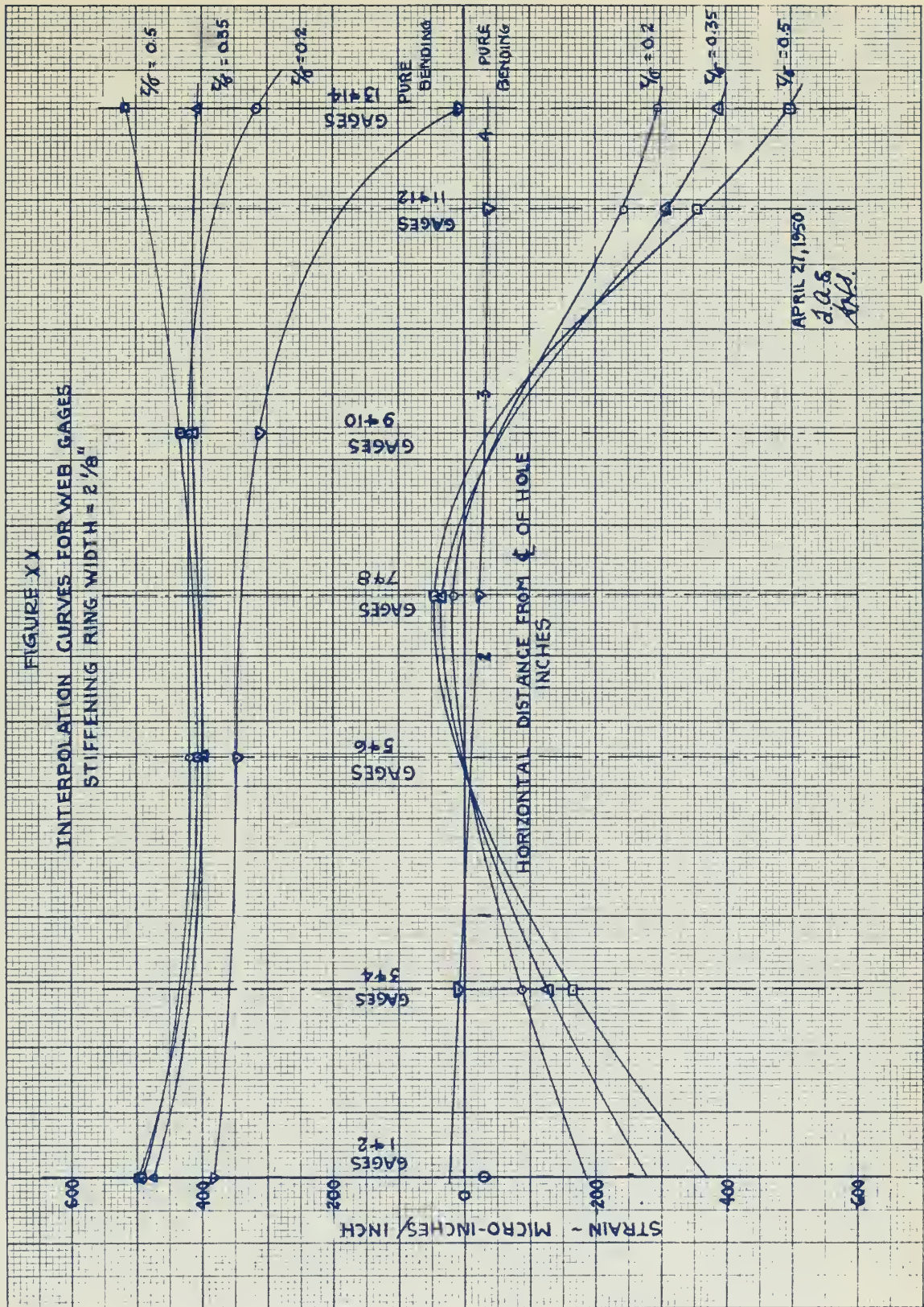












Figure XXII

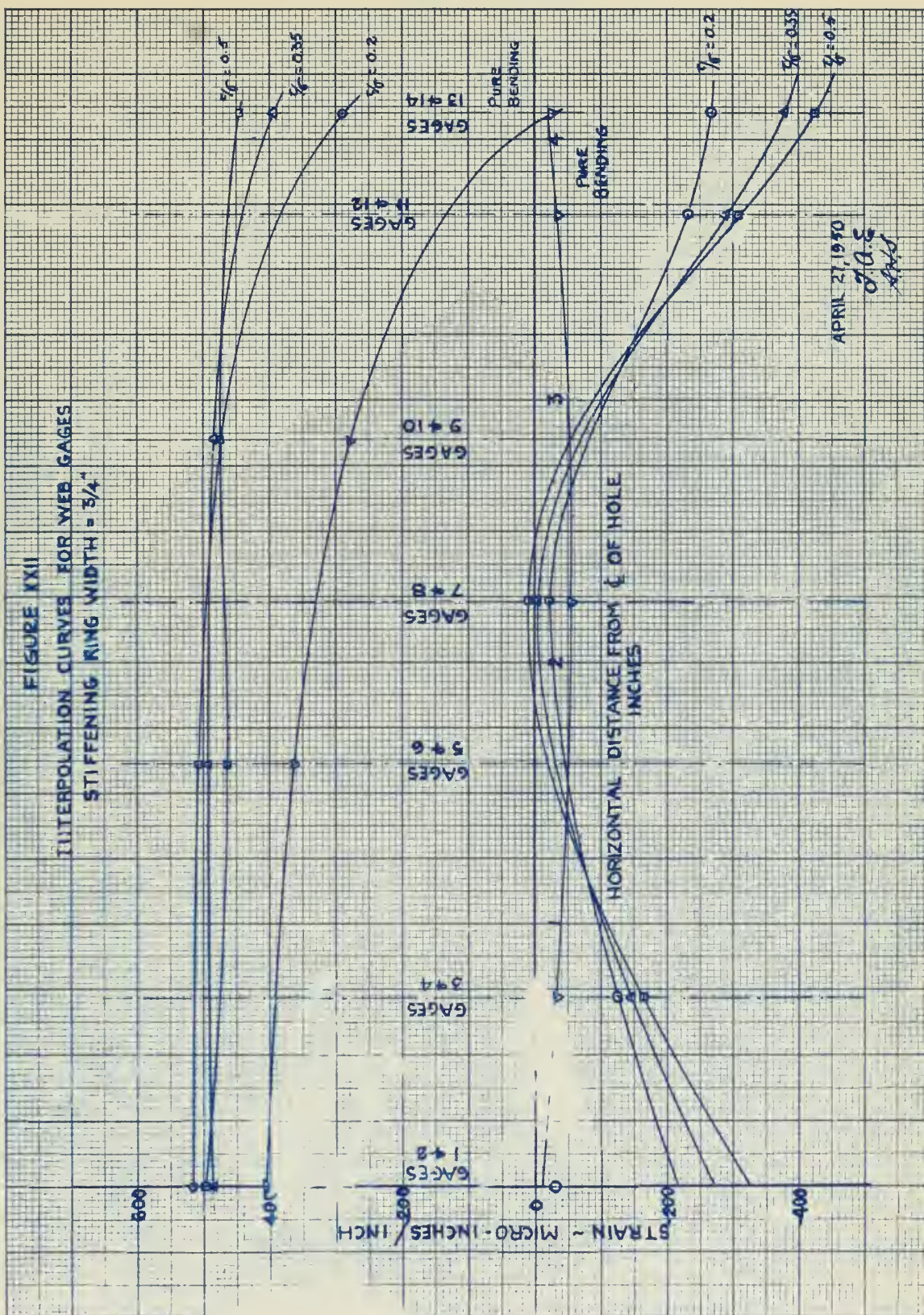






Figure XXIII

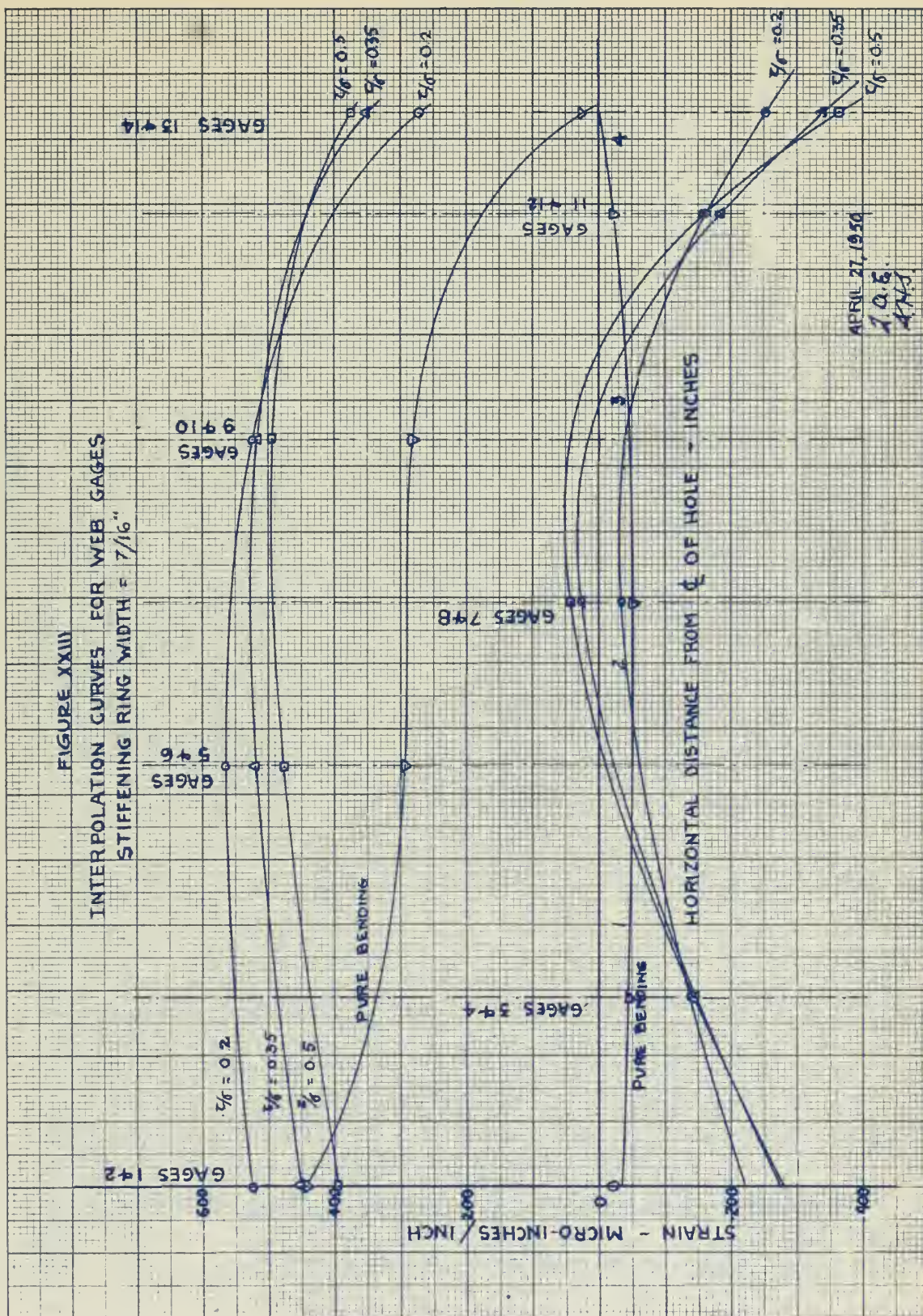
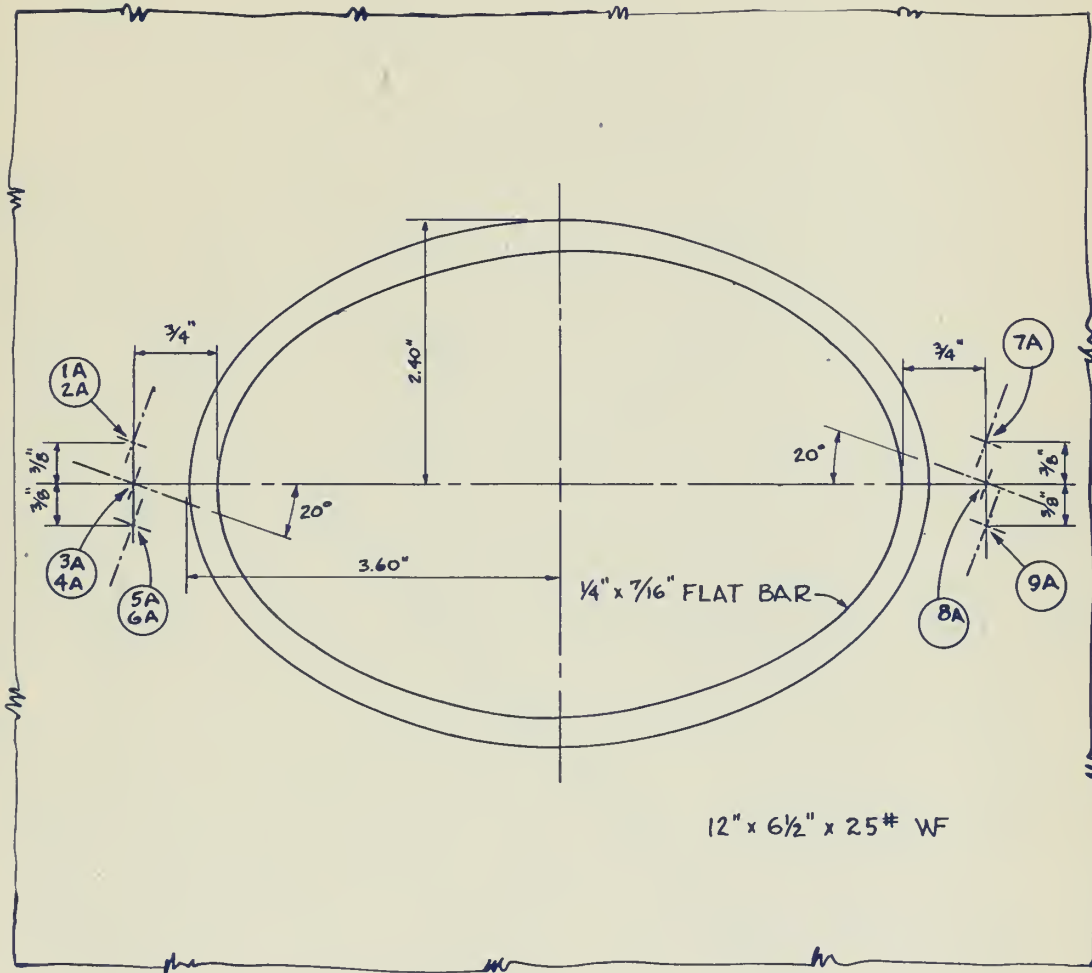




FIGURE XXIV



LOCATION OF SUPPLEMENTARY "A" GAGES  
ON WEB

GAGES 1A, 3A, 5A, 7A, 8A, 9A NEAR SIDE

GAGES 2A, 4A, 6A FAR SIDE

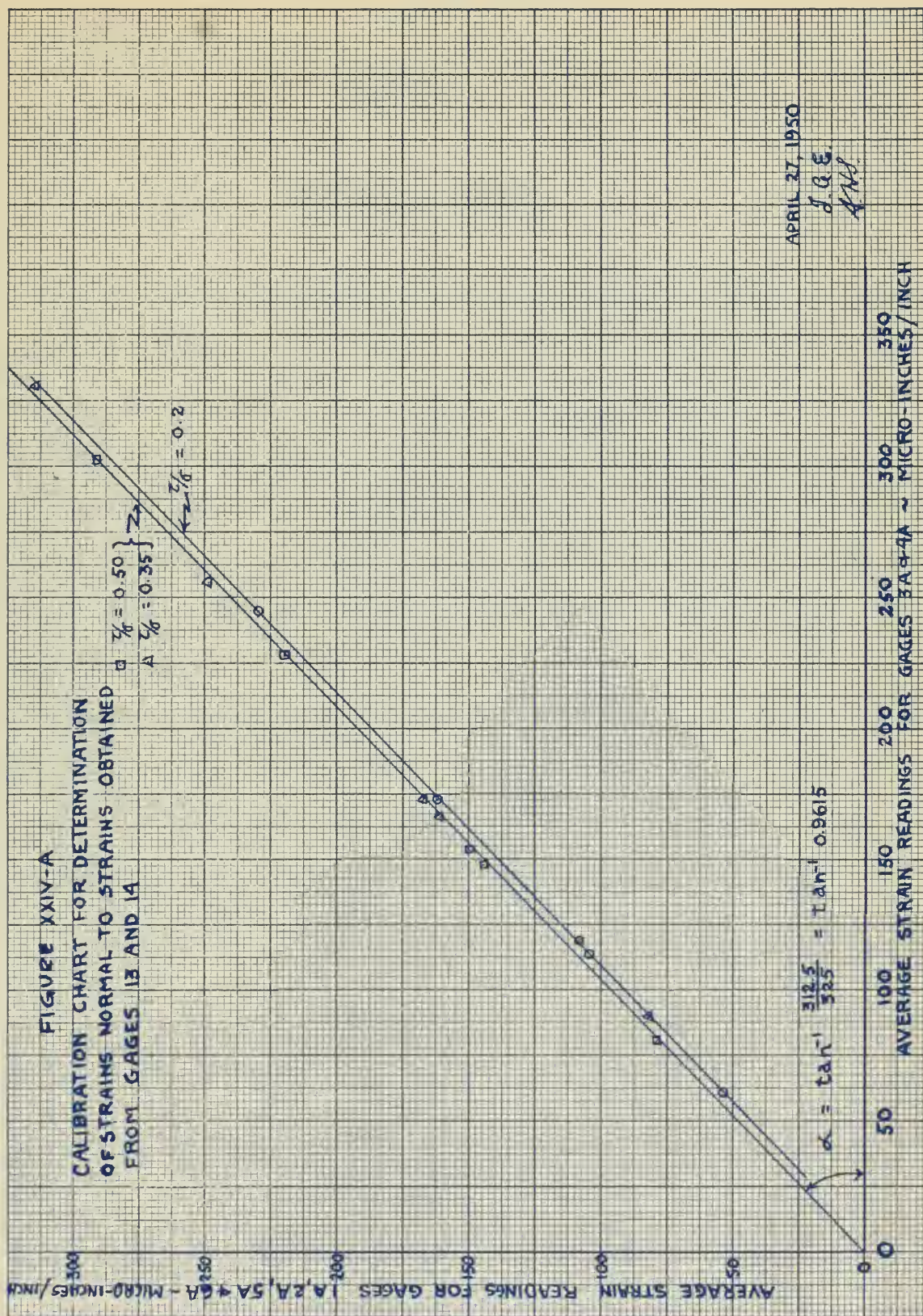
GAGES 3A, 4A SAME LOCATION AS GAGES 13, 14.

APRIL 27, 1950  
A.H.S. d.Q.E.





Figure XXIV -A







## APPENDIX C

### SAMPLE CALCULATIONS

In this section are examples of the calculations for gages on the web, the stiffening ring, and the flanges. Theoretical stress based upon the intact beam is calculated for each example of gage location. The method of deriving the stress from the strain gage readings is given. While the method is quite simple for the stiffening ring and flange gages, consisting merely of multiplying the observed strain by the modulus of the material, the calculation in the case of the web gages is more complicated and will be explained here.

As stated in Appendix B, Details of Procedure, it was not practicable to use rosette gages, because their size conflicted with the desire to locate the web gages as close as possible to the stiffening ring. As is seen diagrammatically from Mohr's Circle, if two stresses normal to each other

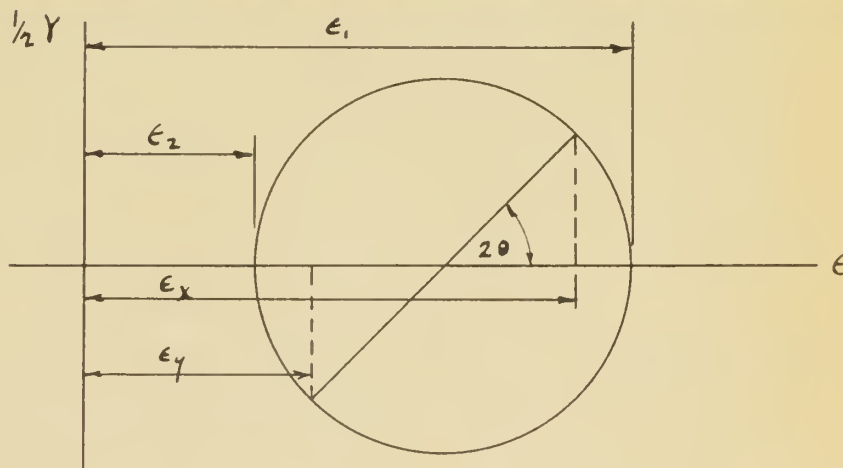


Figure XLIV - Mohr's Circle for Strain



can be measured at a given point, the principal strains can be obtained if  $\theta$  is known, according to the relations

$$\epsilon_1 = \epsilon_x \frac{1 + \cos 2\theta}{2} + \frac{\epsilon_y - \epsilon_x}{2} \sin 2\theta \quad (1)$$

$$\epsilon_2 = \epsilon_x \frac{1 - \cos 2\theta}{2} - \frac{\epsilon_y - \epsilon_x}{2} \sin 2\theta \quad (2)$$

$\theta$  is determined by the stresscoat cracks which are the orthogonal trajectories of the principal tensile strains. To determine the values of  $\theta$  for  $\tau/\sigma = 0.35$ , linear interpolation between the values for 0.20 and 0.50 was used. It should be noted here that  $\theta$  is assumed to remain constant for various breadths of stiffening ring. As a check upon this assumption, at the conclusion of the strain measurement tests a stresscoat diagram was obtained for the 7/16" stiffening ring at  $\tau/\sigma = 0.50$ . This is compared, in Figure XVII, with the original for the 2 1/2" ring. Although there is some deviation between the lines, those in the vicinity of gages 13 and 14 are essentially parallel. This pair of gages is the only pair at which a high stress concentration is indicated, and the above assumption is true for them. The order of magnitude of the results for the other web gages is not altered by the fact that the assumption for them is not strictly correct. Hence in the calculations,  $\theta$  varies only with mode of loading.

With gages 1 and 2, 5 and 6, 9 and 10, and 13 and 14 oriented with their axis  $20^\circ$  below the horizontal, and gages 3 and 4, 7 and 8, and 11





and 12 at  $110^\circ$  below the horizontal, a plot of strains vs. longitudinal distance along the beam could be made for the two sets of gages which would be a fair curve. These are the Interpolation curves, Figures XIX-XXIII.  $\epsilon_x$  is given by the gages at  $20^\circ$ , and  $\epsilon_y$  by the gages at  $110^\circ$ . Thus from these charts, the strain at right angles to any gage can be determined.

Having determined  $\epsilon_1$  and  $\epsilon_2$ , the principal stress,  $\sigma_1$ , is obtained from the formula

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2)^E}{1 - \mu^2} \quad (3)$$

in which, from the results of the tensile test specimen, Young's modulus

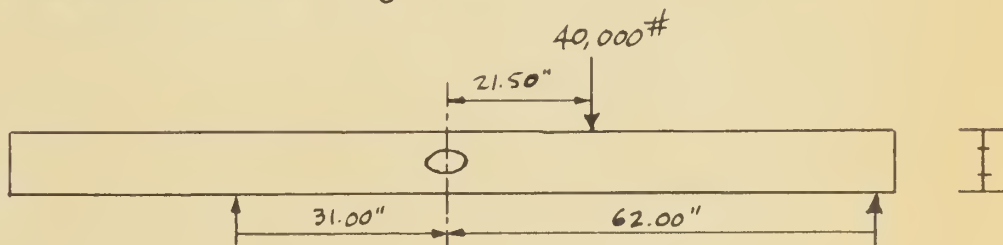
$$E = 30.3 \times 10^6$$

and Poisson's ratio is assumed to be

$$\mu = .29$$

#### A. Web Gage Calculation

- (1) Stress for the intact beam for gages 3 and 4 under loading condition  $\tau/\sigma = 0.35$





Specifications of the intact beam:

Dimensions 12" x 6½" x 25# WF

$$I = 183.4 \text{ ins.}^4$$

$$\text{Depth } C = 11.87"$$

$$\text{Web thickness } b = 0.24"$$

Average flange thickness 0.355"

$$\text{Section Modulus } S = 30.9 \text{ ins.}^3$$

$$M_{R_2} = 0 = 93 R_1 - 1620,000$$

$$R_1 = 17420 \text{ #}$$

$$\text{Lever} = 31.00 - 0.72$$

$$= 30.28"$$

$$\text{Moment} = 17420 \times 30.28$$

$$= 540,000 \text{ in. lbs.}$$

$$y = 2.90"$$

$$\sigma = M_y / I = \frac{540000 \times 2.90}{183.4}$$

$$= 8332 \text{ psi}$$

$$\begin{aligned} \text{Longitudinal Shearing Stress} &= \frac{R_1 Q}{I b} = \tau_L \\ &= \frac{17420 \times 25.98}{183.4 \times .24} \\ &= 10270 \text{ psi.} \end{aligned}$$

$\sigma_1$  = maximum principal stress

$$\begin{aligned} \sigma_1 &= \frac{\sigma}{2} + \sqrt{\left(\frac{\sigma}{2}\right)^2 + \tau_L^2} \\ &= 4166 + 10^3 \sqrt{17.36 + 105.47} \\ &= 15,250 \text{ psi.} \end{aligned}$$



(2) Derived Stress From Gages 3 and 4

$$\tau/\phi = 0.35, \text{ Stiffening Ring } 1\frac{1}{2}"$$

$$\epsilon_1 = \frac{\epsilon_x + \epsilon_y}{2} + \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta$$

$$\epsilon_2 = \frac{\epsilon_x + \epsilon_y}{2} - \frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta$$

$\epsilon_x$  = value obtained from interpolation curves, Figure XXI, upper curves, for  $\tau/\phi = 0.35$ , at line marked "gages 3 and 4."

$\epsilon_y$  = value obtained from interpolation curves, Figure XXI, lower curves for  $\tau/\phi = 0.35$ , at line marked "gages 3 and 4."

$$\epsilon_x = 423 \text{ micro-inches per inch}$$

$$\epsilon_y = -137 \text{ micro-inches per inch}$$

(These values appear also in Table III)

$$\frac{\epsilon_x + \epsilon_y}{2} = 143$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 280$$

$$2\theta = 155.4^\circ$$





$$\sec 2\theta = -1.0998$$

$$\frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta = -307.9$$

$$\begin{aligned}\epsilon_1 &= 143 + (-307.9) \\ &= -164.9 \text{ micro-in. per in.}\end{aligned}$$

$$\begin{aligned}\epsilon_2 &= 143 - (-307.9) \\ &= 450.9 \text{ micro-in. per in.}\end{aligned}$$

$$\sigma_1 = \frac{(\epsilon_{\max} + \mu \epsilon_{\min}) E}{1 - \mu^2}$$

$$\mu = .29$$

$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6$$

$$\epsilon_{\max} + \mu \epsilon_{\min} = 403.1$$

$$\sigma_1 = 403.1 \times 33.082$$

$$= 13330 \text{ psi}$$

(3) Calculation of stress concentration factor:

Stress concentration factor is defined as the ratio of the derived stress to the calculated stress.

$$\text{Factor} = \frac{13330}{15250}$$

$$= 0.87$$



## B. Stiffening Ring Gage Calculation

### (1) Derived Stress

$$\tau/\delta = 0.35, \text{ Stiffening Ring } 1\frac{1}{2}"$$

Gage No. 17

Load 39,945 Lbs.

$$\epsilon_1 = \text{gage reading}$$

$$= 694 \text{ micro-inches per inch}$$

$$E = 29.28 \times 10^6 \text{ psi}$$

$$\sigma = E \epsilon_1$$

$$= 29.28 \times 10^6 \times 694 \times 10^{-6}$$

$$= 19630 \text{ psi.}$$

- (2) Calculated stress is obtained in a manner similar to the web gage.

$$\text{Calculated stress} = 12860 \text{ psi.}$$

$$(3) \text{ Stress concentration factor} = \frac{19630}{12860}$$

$$\text{Factor} = 1.53$$

## C. Flange Gage Calculation

$$(1) \tau/\delta = 0.35, \text{ Stiffening Ring } 1\frac{1}{2}"$$

Gage Nos. 20 and 21





Load 39,945 lbs.

$$\epsilon_1 = \text{gage reading (taken as the average of gages 20 and 21)}$$

$$= 564 \text{ micro-inches per inch}$$

$$E = 30.3 \times 10^6 \text{ psi.}$$

$$\sigma = E \epsilon_1$$

$$= 30.3 \times 10^6 \times 564 \times 10^{-6}$$

$$= 17090 \text{ psi.}$$

(2) Calculated Stress

$$\text{Let } \sigma_c = \text{calculated stress}$$

$$M = \text{Bending moment}$$

$$= \text{Lever} \times R_1$$

$$= 31.00 \times 174.20$$

$$= 540,000 \text{ inch pounds}$$

$$S = 30.9 \text{ ins.}^3$$

$$\sigma_c = \frac{M}{S}$$

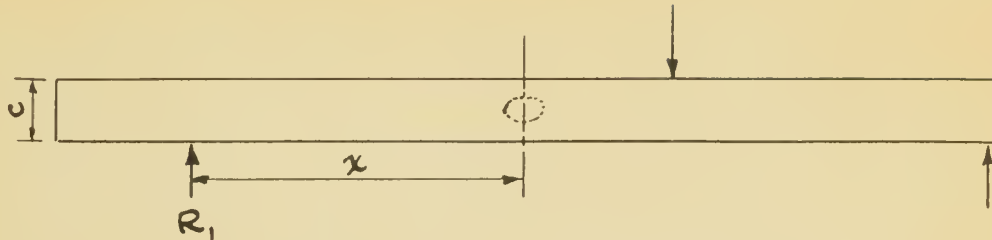
$$= \frac{540,000}{30.9}$$

$$= 17500 \text{ psi.}$$

(3) Stress Concentration Factor = 0.98



D. Calculation for the Loading Condition



$$\delta = \frac{Mc}{2I}$$

$$\tau = \frac{V}{tc} = \frac{R_1}{tc}$$

$$\tau/\delta = \frac{2R_1I}{Mc^2t}$$

but  $M = R_1x$

hence  $\tau/\delta = \frac{2I}{xtc^2}$

for any beam  $\frac{2I}{tc^2} = \text{a constant, } K$

then  $\tau/\delta = \frac{K}{x}$

$$x = K \left( \frac{1}{\tau/\delta} \right)$$

and  $K$  for the beam =  $\frac{2 \times 183.4}{.24 (11.87)^2}$   
 $= 10.85$



Hence  $\chi$  for  $\tau/\phi = .35$  becomes

$$\begin{aligned}\chi_{.35} &= \frac{10.85}{.35} \\ &= 31.00''\end{aligned}$$

#### E. Stress Concentration Factor At Gage 8A

Using Values from Figure XXV

$$(1) \quad \tau/\phi = 0.50$$

$$\epsilon_x = 345 \text{ micro-inches per inch (gage 8A)}$$

$$\epsilon_y = -315 \text{ micro-inches per inch (average, gages 7A and 9A)}$$

$$\frac{\epsilon_x + \epsilon_y}{2} = 15 = D$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 330 = E_1$$

$$2\theta = 49.0^\circ$$

$$\sec 2\theta = 1.5243$$

$$E_1 \sec 2\theta = 503.0 = H$$

$$\epsilon_1 = D + H = 545.0$$

$$\epsilon_2 = D - H = -488.0$$

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2) E}{1 - \mu^2}$$

$$\mu = .29$$

$$E = 30.3 \times 10^6$$





$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6$$

$$\epsilon_1 + \mu \epsilon_2 = 545.0 - 141.5$$

$$= 403.5 \text{ micro-inches per in.}$$

$$\sigma_1 = 403.5 \times 33.082$$

$$= 13350 \text{ psi}$$

$$\text{Calculated Stress } \sigma_c = 10260 \text{ psi.}$$

$$\text{Stress Concentration Factor} = \sigma_1 / \sigma_c$$

$$= 1.30$$

$$(2) \quad \tau / \sigma = 0.20$$

$$\epsilon_x = 293 \text{ micro-inches per inch (Gage 8A)}$$

$$\epsilon_y = -248 \text{ micro-inches per inch (average, gages 7A and 9A)}$$

$$\frac{\epsilon_x + \epsilon_y}{2} = 22.5 = D$$

$$\frac{\epsilon_x - \epsilon_y}{2} = 270 = E_1$$

$$2\theta = 69.0^\circ$$

$$\sec 2\theta = 2.790$$

$$\frac{\epsilon_x - \epsilon_y}{2} \sec 2\theta = 754.7 = H$$



$$\epsilon_1 = D + H = 777.2$$

$$\epsilon_2 = D - H = -732.2$$

$$\sigma_1 = \frac{(\epsilon_1 + \mu \epsilon_2) E}{1 - \mu^2}$$

$$\mu = .29$$

$$\frac{E}{1 - \mu^2} = 33.082 \times 10^6 \text{ where } E = 30.3 \times 10^6$$

$$\epsilon_1 + \mu \epsilon_2 = 777.2 + .29(-732.2)$$

$$= 564.9 \text{ micro-inches per inch}$$

$$\sigma_1 = 564.9 \times 33.082$$

$$= 18,690 \text{ psi.}$$

Calculated stress  $\sigma_c$  ; 8120 psi

$$\text{Stress Concentration Factor} = \frac{\sigma_1}{\sigma_c}$$

$$= 2.30$$





TABLE XII

VALUES OF STRAINS PERPENDICULAR TO STRAINS FOR  
GAGES 13 AND 14 FOR VARIOUS BREADTHS  
OF STIFFENING RING

	$\tau/\sigma = 0.20$			$\tau/\sigma = 0.35$			$\tau/\sigma = 0.50$		
Stiffening Ring Breadth	x x10 <sup>6</sup>	K	y x10 <sup>6</sup>	x x10 <sup>6</sup>	K	y x10 <sup>6</sup>	x x10 <sup>6</sup>	K	y x10 <sup>6</sup>
2½"	315	0.9615	-293	425	0.9615	-409	505	0.9615	-486
2 1/8"	317	↓	-295	405	↓	-389	518	↓	-498
1½"	323	↓	-301	423	↓	-407	515	↓	-495
3/4"	290	↓	-269	394	↓	-379	443	↓	-426
7/16"	272	↓	-252	350	↓	-337	376	↓	-362

K = Slope of Strain vs. Strain line  
from Figure XXIV-A

$$\epsilon_y = -K \epsilon_x \quad \text{for } \tau/\sigma = 0.35 \text{ and } 0.50$$

$$\epsilon_y = -K \epsilon_x + 10 \quad \text{for } \tau/\sigma = 0.20$$



APPENDIX D

ORIGINAL DATA



Stiffening Ring Breadth = 2 1/8"		%/δ = 0.2		Load Increasing		March 22, 1950	
Load	Gage No.	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>
1.80	1	4898	102	5110	110	5338	118
	2	5130	125	5378	123	5650	150
	3	4546	- 02	4525	- 19	4490	- 17
	4	5360	- 48	5285	- 27	5220	- 30
	5	4655	95	4845	95	5050	112
	6	4430	103	4634	101	4855	122
	7	5510	23	5543	10	5565	13
	8	5342	- 20	5320	- 02	5310	03
	9	5483	97	5680	100	5900	120
	10	5044	95	5233	94	5440	115
1.82	11	6490	- 50	6379	- 61	6242	- 73
	12	7295	- 75	7163	- 57	7033	- 71
	13	6813	72	6958	73	7120	90
	14	6975	80	7132	77	7300	92
	15	6524	16	6554	14	6586	18
	16	6325	102	6525	98	6743	120
	17	5912	130	6170	128	6450	155
	18	6140	107	6352	105	6585	129
	19	5840	53	5947	54	6070	70
	20	7105	175	7455	175	7833	208
	21	7328	-170	6974	-174	6590	-210
	22	6575	162	6897	170	7248	193
	23	5600	-186	5245	-169	4880	-200
	24	7105	160	7425	160	7780	193
	25	6250	-170	5920	-160	5573	-190
	26	6430	157	6743	156	7084	188
	27	6374	-154	6063	-157	5720	-185
	28	7054	166	7365	145	7704	184
	29	6674	-164	6352	-158	6003	-189

Table VI. Original Data





Stiffening Ring Breadth = $2\frac{1}{2}$ "		$\frac{1}{3} = .2$		Load Decreasing		March 22, 1950	
Load		27000	18000	9100	0		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5223	-115	5122	-101	5010	4900 02
	2	5510	-140	5390	-120	5261	5132 02
	3	4510	20	4530	20	4550	4551 05
	4	5260	40	5292	32	5320	5367 07
	5	4950	-100	4860	-90	4759	4660 05
	6	4745	-110	4647	-98	4540	4434 04
	7	5552	-13	5542	-10	5540	5515 05
	8	5316	6	5322	6	5325	5348 06
	9	5792	-108	5697	-95	5590	5485 02
	10	5340	-100	5249	-91	5147	5047 03
1.82 ↓	11	6314	82	6375	61	6444	6497 07
	12	7102	69	7165	63	7224	7302 07
	13	7036	-93	6965	-71	6890	6818 05
	14	7212	-88	7136	-75	7060	6980 05
	15	6566	-20	6554	-12	6540	6530 06
	16	6625	-118	6530	-95	6430	6330 05
	17	6307	-143	6183	-124	6050	5920 08
	18	6475	-110	6372	-103	6257	6145 05
	19	6020	-50	5967	-53	5904	5845 05
	20	7645	-188	7475	-170	7290	7104 - 01
1.76 ↓	21	6800	173	6973	173	7154	7335 07
	22	7076	-172	6920	-156	6747	6576 01
	23	5075	195	5246	171	5420	5598 - 02
	24	7610	-170	7453	-157	7278	7107 - 02
	25	5760	187	5920	160	6082	6249 - 01
	26	6920	-164	6769	-151	6600	6430 00
	27	5900	180	6060	160	6223	6386 12
	28	7540	-164	7390	-150	7225	7060 06
	29	6190	187	6350	160	6515	6682 08

Table VI. Original Data



Stiffening Ring Breadth = $2\frac{1}{2}$ "		$\frac{1}{8} = .35$				Load Increasing				March 22, 1950			
Load		0		10000		20000		30000		40000			
Gage Factor	Gage No.	Indicator Reading		Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	
1.80 ↓	1	4902	5000	98	5104	104	5209	105	5310	105	5410	101	
	2	5135	5268	133	5400	132	5528	126	5655	127	5782	127	
	3	4554	4555	1	4530	- 25	4504	- 26	4478	- 26	4452	- 26	
	4	5366	5292	- 74	5250	- 42	5210	- 40	5171	- 39	5132	- 39	
	5	4661	4749	88	4839	90	4929	90	5017	88	5105	88	
	6	4435	4543	108	4648	105	4751	103	4853	102	4955	102	
	7	5516	5568	52	5587	19	5609	22	5620	11	5631	11	
	8	5349	5310	- 39	5309	- 1	5305	- 04	5302	- 03	5299	- 03	
	9	5486	5584	102	5685	101	5787	102	5888	101	5989	101	
	10	5048	5150	102	5249	99	5348	99	5447	99	5546	99	
1.82 ↓	11	6497	6449	- 48	6370	- 79	6289	- 81	6210	- 79	6129	- 79	
	12	7302	7192	- 110	7116	- 76	7041	- 75	6970	- 71	6899	- 71	
	13	6819	6913	94	7020	107	7122	102	7238	116	7349	116	
	14	6980	7090	110	7197	107	7299	102	7403	104	7507	104	
	15	6530	6549	19	6571	22	6592	21	6615	23	6638	23	
	16	6330	6476	146	6617	141	6754	137	6894	140	7034	140	
	17	5921	6086	165	6250	164	6410	160	6575	165	6740	165	
	18	6146	6258	112	6370	112	6480	110	6595	115	6710	115	
	19	5846	5882	36	5922	40	5960	38	6002	42	6044	42	
	20	7103	7240	137	7375	135	7510	135	7647	137	7784	137	
1.76 ↓	21	7334	7197	- 137	7056	- 141	6917	- 139	6780	- 137	6643	- 137	
	22	6576	6692	116	6810	118	6925	115	7041	116	7157	116	
	23	5598	5468	- 130	5340	- 128	5212	- 128	5090	- 122	4968	- 122	
	24	7106	7217	111	7329	112	7440	111	7551	111	7662	111	
	25	6248	6132	- 116	6019	- 113	5902	- 117	5790	- 112	5678	- 112	
	26	6429	6538	109	6644	94	6750	106	6859	109	6968	109	
	27	6385	6275	- 110	6166	- 109	6053	- 113	5945	- 108	5832	- 108	
	28	7059	7165	106	7270	105	7374	104	7480	106	7586	106	
	29	6681	6570	- 111	6456	- 114	6344	- 112	6231	- 113	6118	- 113	

Table VI. Original Data





Stiffening Ring Breadth = $2\frac{1}{2}$ "		Load Decreasing				March 22, 1950	
Gage Factor	Gage No.	30000		20000		10000	
		Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	5211	- 99	5111	-100	5010	-101
	2	5529	-126	5400	-129	5278	-122
	3	4505	27	4532	27	4560	28
	4	5210	39	5250	40	5297	47
	5	4931	- 86	4848	- 83	4759	- 89
	6	4751	-103	4651	-100	4550	-101
	7	5600	20	5633	33	5569	36
	8	5305	3	5305	0	5310	5
	9	5791	- 97	5694	- 97	5596	- 98
	10	5352	- 95	5256	- 96	5150	-106
1.82 ↓	11	6282	72	6364	82	6449	85
	12	7046	76	7117	71	7191	74
	13	7127	-101	7021	-106	6918	-103
	14	7299	-104	7194	-105	7091	-103
	15	6590	- 25	6566	- 24	6545	- 21
	16	6754	-140	6615	-137	6478	-137
	17	6417	-158	6256	-161	6095	-161
	18	6490	-105	6382	-108	6270	-112
	19	5969	- 33	5933	- 36	5899	- 34
	20	7520	-127	7390	-130	7256	-133
1.76 ↓	21	6916	136	7053	137	7196	143
	22	6935	-106	6823	-112	6710	-113
	23	5212	122	5340	128	5469	129
	24	7451	-100	7347	-104	7236	-111
	25	5902	112	6017	115	6130	113
	26	6762	- 97	6662	-100	6554	-108
	27	6051	106	6160	109	6276	116
	28	7388	- 92	7289	- 99	7182	-107
	29	6341	110	6453	112	6570	117

Table VI. Original Data



Stiffening Ring Breadth = $2\frac{1}{2}$ "		$\% = .5$						Load Increasing			March 23, 1950		
Load	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	4892	107	5102	103	5210	108	5315	105	5412	138	5550	133
	2	5125	148	5412	139	5550	138	5683	133	5815	138	5950	133
	3	4540	8	4510	-38	4470	-40	4440	-30	4410	-40	4380	-30
	4	5350	-85	5221	-44	5180	-41	5128	-52	5075	-41	5023	-52
	5	4651	82	4833	90	4924	91	5013	89	5102	91	5191	89
	6	4426	119	4655	110	4764	109	4872	108	4981	109	5090	108
	7	5506	69	5592	17	5608	16	5632	24	5656	16	5680	24
	8	5330	-37	5300	07	5304	04	5300	04	5296	04	5292	04
	9	5479	106	5690	115	5795	105	5900	105	6005	105	6110	105
	10	5040	113	5256	103	5360	103	5470	110	5580	103	5690	110
1.82 ↓	11	6485	-55	6330	-100	6234	-96	6127	-107	6021	-96	5914	-80
	12	7286	-123	7080	-83	7000	-80	6920	-80	6840	-80	6760	-80
	13	6815	120	7062	127	7190	128	7313	123	7436	129	7559	123
	14	6973	139	7236	124	7365	129	7485	120	7605	129	7725	120
	15	6518	30	6575	27	6606	31	6637	31	6668	31	6699	31
	16	6324	181	6676	171	6846	169	7011	165	7181	169	7351	165
	17	5913	199	6303	191	6496	193	6687	191	6878	193	7069	191
	18	6139	125	6384	120	6505	121	6625	120	6745	121	6865	120
	19	5833	36	5900	31	5930	30	5961	31	5992	30	6023	31
	20	7099	119	7333	115	7450	117	7563	113	7676	117	7789	113
1.76 ↓	21	7387	-117	7150	-120	7033	-120	6913	-120	6793	-120	6673	-120
	22	6630	100	6817	92	6909	92	7000	91	7091	92	7182	91
	23	5665	-102	5460	-103	5360	-100	5261	-99	5161	-100	5061	-99
	24	7160	88	7330	82	7411	81	7495	84	7576	81	7656	84
	25	6300	-90	6124	-86	6037	-87	5950	-87	5863	-87	5776	-87
	26	6448	82	6610	80	6685	75	6762	77	6839	75	6916	77
	27	6402	-82	6240	-80	6155	-85	6072	-83	5989	-85	5906	-83
	28	7070	85	7232	77	7306	74	7382	76	7456	74	7530	76
	29	6700	-83	6533	84	6450	-83	6367	-83	6284	-83	6201	-83

Table VI. Original Data





Stiffening Ring Breadth = 2 1/2"			ε/δ = .5		Load Decreasing			March 23, 1950	
Load		33000	22000		11000		0		
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	From Original Reading
1.80 ↓	1	5210	-105	5110	-100	5003	-107	4892	00
	2	5550	-133	5411	-139	5274	-137	5127	02
	3	4470	30	4516	46	4552	36	4549	09
	4	5180	52	5219	39	5264	45	5359	09
	5	4927	-86	4840	-87	4750	-90	4654	03
	6	4766	-106	4659	-107	4545	-114	4430	04
	7	5606	-26	5595	-11	5578	-17	5510	04
	8	5303	-3	5293	-10	5291	-2	5338	08
	9	5800	-100	5695	-105	5590	-105	5480	01
	10	5365	-105	5263	-102	5159	-104	5042	02
1.82 ↓	11	6229	102	6321	108	6420	101	6485	00
	12	7000	80	7080	80	7165	85	7293	07
	13	7179	-134	7052	-127	6928	-124	6804	11
	14	7356	-129	7226	-130	7105	-121	6970	-03
	15	6604	-33	6571	-33	6550	-21	6525	07
	16	6840	-171	6666	-174	6500	-166	6320	-04
	17	6496	-191	6303	-191	6115	-188	5912	-01
	18	6508	-117	6389	-119	6270	-119	6140	01
	19	5933	-28	5902	-31	5876	-26	5838	05
	20	7452	-111	7342	-110	7229	-113	7100	01
1.76 ↓	21	7030	117	7150	120	7270	120	7392	05
	22	6913	-87	6827	-85	6736	-91	6630	00
	23	5364	103	5470	106	5575	105	5684	19
	24	7420	-75	7340	-80	7260	-80	7160	00
	25								
	26	6692	-68	6620	-72	6541	-79	6450	02
	27	6154	82	6238	84	6320	82	6408	06
	28	7313	-69	7243	-70	7168	-75	7073	03
	29	6450	83	6532	82	6619	87	6705	05

### Table VI. Original Data





Stiffening Ring Breadth = $2\frac{1}{2}$ "		Pure Bending			Load Increasing			March 23, 1950	
Load	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80	1	4882	86	5058	90	5150	92	5235	85
	2	5122	98	5310	90	5403	93	5495	92
	3	4530	18	4564	16	4587	23	4617	30
	4	5345	- 21	5310	- 14	5292	- 18	5260	- 32
	5	4646	85	4818	87	4907	89	4990	83
	6	4423	81	4583	79	4663	80	4740	77
	7	5497	13	5518	08	5532	14	5555	23
	8	5324	- 29	5274	- 21	5250	- 24	5210	- 40
	9	5473	77	5628	78	5708	80	5780	72
	10	5035	70	5177	72	5250	73	5322	72
1.82	11	6475	22	6506	9	6518	12	6537	19
	12	7287	- 44	7215	- 28	7180	- 35	7133	- 47
	13	6793	- 18	6770	- 05	6760	- 10	6743	- 17
	14	6965	20	7000	15	7010	10	7025	15
	15	6520	02	6525	03	6527	02	6524	- 03
	16	6310	04	6315	01	6317	02	6318	01
	17	5902	33	5968	33	6000	32	6030	30
	18	6130	73	6280	77	6353	73	6426	73
	19	5833	76	5985	76	6060	75	6134	74
	20	7103	235	7570	232	7801	231	8029	228
	21	7232	-237	6767	-228	6533	-234	6302	-231
	22	6478	234	6945	233	7173	228	7401	228
	23	5495	-240	5030	-225	4798	-232	4566	-242
	24	6993	245	7483	245	7726	243	7965	239
	25								
	26	6303	246	6549	241	7026	236	7263	237
	27	6240	-240	5763	-239	5523	-240	5285	-238
	28	6929	241	7410	240	7645	235	7881	236
	29	6540	-246	6055	-239	5811	-244	5570	-241

Table VI. Original Data



Stiffening Ring Breadth = $2\frac{1}{2}$ "				Pure Bending			Load Decreasing			March 23, 1950	
Gage Factor	Gage No.	33000		22000		11000		0			
		Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5160	- 75	5073	- 87	4974	- 99	4882	- 99	4882	00
	2	5417	- 78	5325	- 92	5228	- 97	5123	- 97	5123	01
	3	4590	- 27	4570	- 20	4550	- 20	4534	- 20	4534	04
	4	5292	32	5313	21	5329	16	5350	16	5350	05
	5	4920	- 70	4835	- 85	4740	- 95	4649	- 95	4649	03
	6	4674	- 66	4599	- 75	4510	- 89	4426	- 89	4426	03
	7	5531	- 24	5519	- 12	5510	- 9	5500	- 9	5500	03
	8	5248	38	5277	29	5299	22	5330	22	5330	06
	9	5720	- 60	5646	- 74	5560	- 86	5474	- 86	5474	01
	10	5262	- 60	5192	- 70	5114	- 78	5040	- 78	5040	05
1.82 ↓	11	6514	- 23	6500	- 14	6500	0	6484	0	6484	09
	12	7170	37	7211	41	7243	32	7290	32	7290	03
	13	6761	18	6775	14	6780	5	6799	5	6799	06
	14	7013	- 12	7000	- 13	6990	- 10	6972	- 10	6972	07
	15	6522	- 2	6522	0	6525	3	6528	3	6528	08
	16	6319	1	6319	0	6318	1	6319	1	6319	09
	17	6008	- 22	5979	- 29	5943	- 36	5909	- 36	5909	07
	18	6370	- 56	6399	- 29	6214	- 17	6133	- 17	6133	03
	19	6075	- 59	6002	- 73	5920	- 82	5837	- 82	5837	04
	20	7820	- 209	7591	- 229	7349	- 242	7100	- 242	7100	03
1.76 ↓	21	6528	226	6760	232	7000	240	7243	240	7243	09
	22	7193	- 208	6967	- 226	6722	- 245	6474	- 245	6474	04
	23	4796	230	5040	244	5289	249	5541	249	5541	46
	24	7750	- 215	7510	- 240	7252	- 248	6991	- 248	6991	03
	25										
	26	7050	- 213	6815	- 235	6560	- 255	6302	- 255	6302	01
	27	5519	234	5760	241	6003	243	6252	243	6252	12
	28	7670	- 211	7432	- 248	7184	- 248	6928	- 248	6928	01
	29	5803	233	6050	247	6299	249	6550	249	6550	10

Table VI. Original Data





Stiffening Ring Breadth = 2-1/8"		$\gamma/5 = 0.2$		Load Increasing		March 28, 1950	
Load	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
		0	9100	18000	27000	37740	
1.80 ↓	1	4865	105	5082	112	5190	108
	2	5122	128	5373	123	5500	127
	3	4536	07	4530	- 13	4520	- 10
	4	5353	- 58	5270	- 25	5242	- 28
	5	4660	94	4851	97	4950	99
	6	4458	102	4664	104	4770	106
	7	5521	39	5573	13	5585	12
	8	5382	- 32	5348	- 02	5345	- 03
	9	5502	101	5708	105	5810	102
	10	5090	100	5286	96	5385	99
1.82 ↓	11	6536	- 33	6446	- 57	6388	- 58
	12	7340	- 88	7200	- 52	7139	- 61
	13	6887	71	7032	74	7106	74
	14	7060	80	7218	78	7295	77
	15	6840	10	6870	20	6882	12
	16	6390	107	6598	101	6697	99
	17	5925	135	6189	129	6318	129
	18	6185	115	6410	110	6520	110
	19	5902	58	6020	60	6080	60
	20	7110	181	7470	179	7648	178
1.76 ↓	21	7333	-174	6986	-173	6810	-176
	22	6575	167	6904	162	7070	166
	23						
	24	7110	165	7440	165	7602	162
	25	6239	-162	5920	-157	5763	-157
	26	6430	165	6752	157	6913	161
	27	6373	-158	6062	-153	5905	-157
	28	7062	163	7382	157	7540	158
	29	6673	-161	6357	-155	6200	-157

Table VII. Original Data



Stiffening Ring Breadth = 2-1/8"				$\epsilon/6 = .2$				Load Decreasing				March 28, 1950			
Load				27000				18000				9100			
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5200	-120	5082	-118	4973	-109	4863	-109	4863	-109	4863	-109	4863	- 02
	2	5510	-140	5372	-138	5249	-123	5120	-123	5120	-123	5120	-123	5120	- 02
	3	4515	15	4525	10	4545	20	4540	20	4540	20	4540	20	4540	- 04
	4	5248	38	5270	22	5300	30	5358	30	5358	30	5358	30	5358	05
	5	4960	-105	4854	-106	4756	-98	4658	-98	4658	-98	4658	-98	4658	- 02
	6	4778	-115	4664	-114	4560	-104	4455	-104	4455	-104	4455	-104	4455	- 03
	7	5580	-20	5562	-18	5558	-04	5523	-04	5523	-04	5523	-04	5523	02
	8	5348	08	5343	-05	5350	07	5382	07	5382	07	5382	07	5382	00
	9	5822	-110	5710	-112	5608	-102	5505	-102	5505	-102	5505	-102	5505	03
	10	5394	-106	5289	-105	5190	-99	5089	-99	5089	-99	5089	-99	5089	- 01
1.82 ↓	11	6380	60	6435	55	6500	65	6543	65	6543	65	6543	65	6543	07
	12	7140	70	7191	51	7253	62	7344	62	7344	62	7344	62	7344	04
	13	7105	-90	7028	-77	6953	-75	6884	-75	6884	-75	6884	-75	6884	- 03
	14	7294	-96	7210	-84	7134	-76	7054	-76	7054	-76	7054	-76	7054	- 06
	15	6875	-25	6855	-20	6845	-10	6833	-10	6833	-10	6833	-10	6833	- 07
	16	6693	-124	6590	-103	6492	-98	6390	-98	6390	-98	6390	-98	6390	00
	17	6322	-148	6185	-137	6060	-125	5925	-125	5925	-125	5925	-125	5925	00
	18	6535	-115	6415	-120	6305	-110	6191	-110	6191	-110	6191	-110	6191	06
	19	6095	-55	6029	-66	5968	-61	5910	-61	5910	-61	5910	-61	5910	08
	20	7662	-193	7475	-187	7293	-182	7108	-182	7108	-182	7108	-182	7108	- 02
1.76 ↓	21	6813	203	6984	171	7163	179	7348	179	7348	179	7348	179	7348	15
	22	7090	-175	6913	-177	6747	-166	6573	-166	6573	-166	6573	-166	6573	- 02
	23														
	24	7623	-177	7450	-173	7280	-170	7110	-170	7110	-170	7110	-170	7110	00
	25	5766	183	5920	154	6082	162	6250	162	6250	162	6250	162	6250	11
	26	6932	-168	6760	-172	6600	-160	6430	-160	6430	-160	6430	-160	6430	00
	27	5905	180	6058	153	6220	162	6383	162	6383	162	6383	162	6383	10
	28	7560	-170	7390	-170	7230	-160	7061	-160	7061	-160	7061	-160	7061	01
	29	6200	188	6350	150	6514	164	6682	164	6682	164	6682	164	6682	09

Table VII. Original Data





Stiffening Ring Breadth = 2-1/8"			$\mu = .35$		Load Increasing				March 29, 1950			
Load	Gage	Indicator	0		10000		20000		30000		40000	
Gage Factor	Gage No.	Indicator Reading	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	4866	4970	104	5078	108	5181	103	5286	105	5389	105
	2	5124	5260	136	5392	132	5525	133	5655	130	5785	130
	3	4540	4560	20	4537	- 23	4512	- 25	4489	- 23	4466	- 23
	4	5352	5267	- 85	5227	- 40	5189	- 38	5148	- 41	5107	- 41
	5	4660	4750	90	4843	93	4937	94	5027	90	5117	90
	6	4460	4570	110	4677	107	4784	107	4890	106	5000	106
1.82 ↓	7	5530	5600	70	5620	20	5637	17	5655	18	5673	18
	8	5377	5330	- 47	5328	- 02	5325	- 03	5321	- 04	5317	- 04
	9	5510	5608	98	5712	104	5816	104	5920	104	6024	104
	10	5090	5200	110	5300	100	5402	102	5503	101	5605	101
	11	6548	6513	- 35	6430	- 83	6355	- 75	6279	- 76	6203	- 76
	12	7340	7217	- 123	7144	- 73	7067	- 77	6992	- 75	6917	- 75
	13	6887	6985	98	7090	105	7194	104	7300	106	7406	106
	14	7090	7172	82	7280	108	7385	105	7490	105	7595	105
	15	6830	6850	20	6871	21	6893	22	6915	22	6937	22
	16	6398	6547	149	6687	140	6827	140	6966	139	7105	139
	17	5930	6100	170	6264	164	6429	165	6591	162	6753	162
	18	6196	6311	115	6428	117	6541	113	6656	115	6771	115
	19	5910	5950	40	5990	40	6032	42	6073	41	6115	41
1.76 ↓	20	7114	7253	139	7394	141	7532	138	7670	138	7808	138
	21	7343	7205	- 138	7065	- 140	6925	- 140	6785	- 140	6645	- 140
	22	6578	6700	122	6820	120	6939	119	7058	119	7177	119
	23	5570	5440	- 130	5312	- 128	5185	- 127	5060	- 125	4935	- 125
	24	7112	7228	116	7342	114	7457	115	7570	113	7683	113
	25	6248	6130	- 118	6016	- 114	5900	- 116	5788	- 112	5676	- 112
	26	6432	6545	113	6655	110	6764	109	6872	108	6980	108
	27	6584	6274	- 110	6160	- 114	6050	- 110	5940	- 110	5830	- 110
	28	7064	7178	114	7286	108	7393	107	7500	107	7607	107
	29	6683	6570	- 113	6458	- 112	6346	- 112	6233	- 113	6120	- 113

Table VII. Original Data





Stiffening Ring Breadth = 2-1/8"			"6 = .35			Load Decreasing			March 29, 1950		
Load			30000			20000			10000		
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	From Original Reading
1.80 ↓	1	5189	- 97	5089	-100	4980	-109	4864	-109	4864	- 02
	2	5527	-128	5404	-123	5267	-137	5122	-137	5122	- 02
	3	4512	23	4540	28	4568	28	4544	28	4544	04
	4	5189	41	5234	45	5274	40	5356	40	5356	04
	5	4942	- 85	4857	- 85	4760	- 97	4660	- 97	4660	00
	6	4788	-102	4688	-100	4577	-111	4457	-111	4457	- 03
1.82 ↓	7	5636	- 19	5619	- 17	5600	- 19	5530	- 19	5530	00
	8	5326	05	5330	04	5333	03	5378	03	5378	01
	9	5822	- 98	5727	- 95	5618	-109	5508	-109	5508	- 02
	10	5410	- 93	5313	- 97	5209	-104	5090	-104	5090	00
	11	6350	71	6434	84	6516	82	6547	82	6547	- 01
	12	7070	78	7142	72	7217	75	7338	75	7338	- 02
1.76 ↓	13	7198	-102	7092	-106	6983	-109	6881	-109	6881	- 06
	14	7382	-108	7280	-102	7170	-110	7052	-110	7052	- 38
	15	6890	- 25	6868	- 22	6840	- 28	6820	- 28	6820	- 10
	16	6825	-141	6687	-138	6540	-147	6390	-147	6390	- 08
	17	6430	-161	6270	-160	6100	-170	5923	-170	5923	- 07
	18	6550	-106	6442	-108	6316	-126	6190	-126	6190	- 06
	19	6040	- 33	6008	- 32	5953	- 55	5903	- 55	5903	- 07
	20	7543	-127	7413	-130	7260	-153	7109	-153	7109	- 05
	21	6925	140	7065	140	7203	138	7344	138	7344	01
	22	6950	-108	6840	-110	6707	-133	6572	-133	6572	- 06
	23	5186	126	5314	128	5440	126	5573	126	5573	03
	24	7470	-100	7364	-106	7237	-127	7106	-127	7106	- 06
	25	5900	112	6016	116	6130	114	6248	114	6248	00
	26	6778	- 94	6678	-100	6555	-123	6429	-123	6429	- 03
	27	6050	110	6162	112	6272	110	6383	110	6383	- 01
	28	7407	- 93	7308	- 99	7185	-123	7060	-123	7060	- 04
	29	6345	112	6460	115	6570	110	6684	110	6684	01

Table VII. Original Data



Stiffening Ring Breadth = 2-1/8"				$\tau/\phi = .5$				Load Increasing				March 29, 1950			
Load		0		11000		22000		33000		44000					
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment	Indicator Reading	Strain Increment
1.80 ↓	1	4852	4963	5073	111	5180	110	5288	107	5388	108	5488	107	5588	108
	2	5119	5260	5402	141	5542	142	5680	140	5820	138	5960	140	6100	138
	3	4539	4553	4520	14	4480	- 33	4445	- 40	4405	- 35	4370	- 40	4335	- 35
	4	5350	5246	5202	-104	5158	- 44	5115	- 44	5072	- 43	5029	- 44	4986	- 43
	5	4657	4743	4838	86	4930	95	5022	92	5114	92	5206	92	5298	92
	6	4453	4568	4682	115	4793	114	4905	111	5017	112	5129	111	5241	112
	7	5526	5604	5624	78	5645	20	5665	21	5685	20	5705	21	5725	20
	8	5372	5312	5320	- 60	5320	08	5322	00	5324	02	5326	00	5328	02
	9	5505	5606	5717	101	5826	111	5933	109	6040	107	6147	109	6254	107
	10	5086	5200	5307	114	5412	107	5520	105	5628	108	5736	105	5844	108
1.82 ↓	11	6543	6497	6400	- 46	6305	- 97	6217	- 95	6124	- 88	6036	- 82	5948	- 88
	12	7336	7193	7110	-143	7028	- 83	6950	- 82	6872	- 78	6794	- 82	6716	- 78
	13	6885	7005	7136	120	7265	131	7400	129	7534	135	7669	129	7804	135
	14	7051	7183	7312	132	7440	129	7574	128	7708	134	7842	128	7976	134
	15	6819	6835	6862	16	6890	27	6920	28	6950	30	6980	28	7010	30
	16	6392	6573	6747	181	6919	174	7097	172	7275	178	7453	172	7631	178
	17	5924	6120	6317	196	6510	197	6710	193	6909	200	7109	193	7308	200
	18	6190	6316	6440	126	6563	124	6691	123	6819	128	6947	123	7075	128
	19	5902	5932	5968	30	6000	36	6040	32	6080	40	6120	32	6160	40
	20	7110	7228	7345	118	7461	117	7585	116	7709	124	7833	116	7957	124
1.76 ↓	21	7342	7220	7101	-122	6980	-119	6870	-121	6759	-110	6648	-121	6537	-110
	22	6570	6664	6760	94	6853	96	6953	93	7053	100	7153	93	7253	100
	23	5570	5466	5365	-104	5261	-101	5167	-104	5067	- 94	4967	-104	4867	- 94
	24	7104	7190	7275	86	7360	85	7451	85	7541	91	7631	85	7721	91
	25	6245	6151	6066	- 94	5977	- 85	5898	- 89	5819	- 79	5739	- 89	5659	- 79
	26	6428	6510	6590	82	6668	80	6754	78	6840	86	6926	78	7012	86
	27	6382	6300	6218	- 82	6132	- 82	6058	- 86	5984	- 74	5910	- 86	5836	- 74
	28	7055	7140	7220	85	7297	80	7380	77	7462	83	7544	77	7626	83
	29	6683	6600	6516	- 83	6432	- 84	6355	- 84	6271	- 77	6187	- 84	6103	- 77

Table VII. Original Data





Stiffening Ring Breadth = 2-1/8"			Load Decreasing			March 29, 1950		
Load			22000			0		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Indicator Reading	From Original Reading
1.80 ↓	1	5190	- 98	5082	-108	4975	4864	12
	2	5546	-114	5410	-136	5270	5120	01
	3	4492	47	4520	28	4559	4540	01
	4	5159	44	5210	51	5256	5357	07
	5	4938	- 84	4849	- 89	4756	4660	03
	6	4800	-105	4690	-110	4578	4456	03
	7	5652	- 13	5625	- 27	5608	5527	01
	8	5320	- 02	5322	02	5320	5374	02
	9	5832	-101	5730	-102	5620	5511	06
	10	5420	-100	5317	-103	5210	5089	03
1.82 ↓	11	6305	88	6404	99	6502	6552	09
	12	7032	82	7114	82	7199	7340	04
	13	7271	-129	7138	-133	7010	6887	02
	14	7440	-154	7312	-128	7185	7051	00
	15	6886	- 34	6855	- 31	6827	6803	16
	16	6920	-177	6748	-172	6576	6397	05
	17	6518	-192	6324	-194	6131	5930	06
	18	6573	-118	6453	-120	6330	6200	10
	19	6012	- 28	5981	- 31	5950	5910	08
	20	7473	-112	7360	-113	7241	7111	01
1.76 ↓	21	6984	114	7102	118	7222	7345	03
	22	6866	- 87	6776	- 90	6680	6573	03
	23	5266	99	5366	100	5470	5580	10
	24	7373	- 78	7293	- 80	7210	7110	06
	25	5980	82	6067	87	6155	6249	04
	26	6682	- 72	6609	- 73	6528	6432	04
	27	6136	78	6220	84	6303	6390	08
	28	7310	- 70	7236	- 74	7158	7060	05
	29	6435	80	6518	83	6603	6691	08

Table VII. Original Data



Stiffening Ring Breadth = 2-1/8"				Pure Bending			Load Increasing			March 29, 1950		
Load				11000			22000			33000		
Gage Factor	Gage No.	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading
1.80 ↓	1	4857	89	5037	91	5130	93	5223	93	5223	93	5223
	2	5111	99	5304	94	5402	98	5508	98	5508	106	5508
	3	4530	10	4532	-	4531	-	4532	-	4532	1	4532
	4	5341	- 11	5335	5	5345	10	5357	10	5357	12	5357
	5	4650	89	4828	89	4919	91	5011	91	5011	92	5011
	6	4448	82	4610	80	4692	82	4780	82	4780	88	4780
	7	5518	4	5506	- 16	5491	- 15	5485	- 15	5485	6	5485
	8	5355	- 19	5333	-	5335	-	5340	2	5340	5	5340
	9	5501	79	5661	81	5744	83	5832	83	5832	88	5832
	10	5078	73	5220	69	5291	71	5370	71	5370	79	5370
1.82 ↓	11	6542	17	6550	9	6544	-	6545	6	6545	1	6545
	12	7319	- 38	7268	- 13	7259	-	7249	-	7249	- 10	7249
	13	6870	- 16	6844	- 10	6837	-	6830	-	6830	-	6830
	14	7044	16	7070	10	7084	14	7104	14	7104	20	7104
	15	6783	3	6787	1	6790	3	6800	3	6800	10	6800
	16	6380	0	6376	-	6379	3	6381	3	6381	2	6381
	17	5915	33	5976	28	6010	34	6047	34	6047	37	6047
	18	6184	76	6332	72	6411	79	6491	79	6491	80	6491
	19	5895	75	6049	79	6129	80	6212	80	6212	83	6212
	20	7108	234	7580	238	7812	232	8050	232	8050	238	8050
1.76 ↓	21	7320	-239	6843	-238	6611	-232	6382	-232	6382	-229	6382
	22	6567	234	7038	237	7271	233	7511	233	7511	240	7511
	23	5553	-244	5062	-247	4824	-238	4590	-238	4590	-234	4590
	24	7103	248	7597	246	7841	244	8091	244	8091	250	8091
	25	6220	-242	5736	-242	5500	-236	5265	-236	5265	-235	5265
	26	6425	245	6911	241	7154	243	7402	243	7402	248	7402
	27	6362	-243	5872	-247	5634	-238	5400	-238	5400	-234	5400
	28	7053	244	7538	241	7779	241	8022	241	8022	243	8022
	29	6665	-250	6169	-246	5928	-241	5690	-241	5690	-238	5690

Table VII. Original Data





Stiffening Ring Breadth = 2-1/8"			Pure Bending			Load Decreasing			March 29, 1950	
Gage Factor	Gage No.	Indicator Reading	33000			22000			11000	
			Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Indicator Reading	From Original Reading
1.80 ↓	1	5145	- 78	5055	- 90	4958	- 97	4860	4860	03
	2	5420	- 88	5320	-100	5220	-100	5113	5113	02
	3	4530	- 2	4536	- 6	4541	- 5	4531	4531	01
	4	5350	- 7	5340	-10	5336	- 4	5347	5347	06
	5	4983	- 28	4849	-134	4751	- 98	4658	4658	08
	6	4706	- 74	4623	- 83	4540	- 83	4450	4450	02
	7	5490	5	5504	14	5525	21	5522	5522	04
	8	5340	0	5338	- 2	5340	2	5360	5360	05
1.82 ↓	9	5761	- 71	5680	- 81	5592	- 88	5505	5505	04
	10	5307	- 63	5237	- 70	5160	- 77	5081	5081	03
	11	6538	- 7	6540	- 2	6555	15	6545	6545	03
	12	7258	9	7268	10	7282	14	7321	7321	02
	13	6842	12	6854	12	6862	8	6878	6878	08
	14	7090	- 14	7074	- 16	7066	- 8	7051	7051	07
	15	6789	- 11	6782	- 7	6788	6	6789	6789	06
	16	6380	- 1	6380	0	6387	7	6387	6387	07
1.76 ↓	17	6020	- 27	5990	- 30	5958	- 32	5922	5922	07
	18	6430	- 61	6354	- 76	6272	- 82	6190	6190	06
	19	6148	- 64	6069	- 79	5983	- 86	5900	5900	05
	20	7836	-214	7601	-235	7356	-245	7106	7106	- 02
	21	6607	225	6840	233	7082	242	7330	7330	- 10
	22	7298	-213	7061	-237	6818	-243	6564	6564	- 03
	23	4820	230	5060	240	5310	250	5561	5561	08
	24	7869	-222	7625	-244	7367	-258	7105	7105	02
	25	5495	230	5732	237	5980	248	6230	6230	10
	26	7180	-222	6940	-240	6688	-252	6427	6427	02
	27	5630	230	5870	240	6120	250	6371	6371	09
	28	7801	-221	7563	-238	7311	-252	7052	7052	- 01
	29	5922	232	6161	239	6418	257	6672	6672	07

Table VII. Original Data









Stiffening Ring Breadth = $1\frac{1}{2}$ "			$\tau/s = .2$			Load Decreasing			April 1, 1950		
I load			27030			18010			9065		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5084	-117	4975	-109	4860	-115	4740	-115	4740	13
	2	5372	-143	5247	-125	5115	-132	4991	-132	4991	14
	3	4353	23	4379	26	4400	21	4398	21	4398	20
	4	5105	45	5139	34	5170	31	5229	31	5229	18
	5	4859	-109	4755	-104	4650	-105	4540	-105	4540	15
	6	4685	-117	4580	-105	4471	-109	4365	-109	4365	14
	7	5460	-13	5457	-03	5452	-05	5420	-05	5420	17
	8	5203	13	5212	9	5220	8	5251	8	5251	16
	9	5715	-111	5610	-105	5502	-108	5400	-108	5400	15
	10	5275	-108	5179	-96	5078	-101	4972	-101	4972	16
1.82 ↓	11	6318	60	6379	61	6440	61	6480	61	6480	14
	12	7020	80	7083	63	7144	61	7232	61	7232	18
	13	7003	-81	6935	-68	6863	-72	6785	-72	6785	15
	14	7189	-92	7111	-78	7032	-79	6960	-79	6960	12
	15	7290	-15	7280	-10	7270	-10	7260	-10	7260	08
	16	6614	-124	6513	-101	6412	-101	6309	-101	6309	16
	17	6259	-151	6120	-139	5988	-132	5850	-132	5850	11
	18	6490	-125	6370	-120	6245	-125	6120	-125	6120	11
	19	6015	-56	5950	-65	5883	-67	5817	-67	5817	10
	20	7562	-198	7382	-180	7199	-183	7010	-183	7010	10
1.76 ↓	21	6854	214	7040	186	7220	180	7405	180	7405	14
	22	7140	-179	6971	-169	6801	-170	6627	-170	6627	12
	23	5092	208	5270	178	5444	174	5623	174	5623	13
	24	7678	-175	7510	-168	7339	-171	7162	-171	7162	10
	25	5783	195	5950	167	6113	163	6285	163	6285	15
	26	6940	-170	6779	-161	6611	-168	6440	-168	6440	10
	27	5900	193	6066	166	6229	163	6395	163	6395	15
	28	7562	-170	7400	-162	7237	-163	7068	-163	7068	08
	29	6208	196	6375	167	6540	165	6710	165	6710	14

Table VIII. Original Data





Stiffening Ring Breadth = $1\frac{1}{2}$ "		$\tau/\phi = .35$				Load Increasing				April 1, 1950	
Gage Factor	Gage No.	0		10005		20010		29980		39945	
		Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80	1	4740	110	4959	109	5065	106	5170	105	5170	105
	2	4990	132	5257	135	5490	133	5523	133	5523	133
	3	4397	16	4384	-29	4355	29	4329	-26	4329	-26
	4	5223	-83	5100	-40	5059	41	5017	-42	5017	-42
	5	4540	100	4740	100	4840	100	4939	99	4939	99
	6	4365	110	4586	111	4696	110	4804	108	4804	108
	7	5421	66	5502	15	5520	18	5535	15	5535	15
	8	5249	-49	5200	0	5197	3	5190	-07	5190	-07
	9	5400	100	5608	108	5715	107	5822	107	5822	107
	10	4971	110	5188	107	5290	102	5394	104	5394	104
1.82	11	6480	-34	6370	-76	6292	78	6218	-74	6218	-74
	12	7227	-118	7033	-76	6960	73	6885	-75	6885	-75
	13	6785	107	6999	107	7100	101	7202	102	7202	102
	14	6960	108	7175	107	7283	108	7390	107	7390	107
	15	7258	16	7295	21	7314	19	7331	17	7331	17
	16	6310	153	6610	147	6756	146	6900	144	6900	144
	17	5850	175	6200	175	6371	171	6544	173	6544	173
	18	6120	125	6372	127	6500	128	6628	128	6628	128
	19	5815	45	5906	46	5951	45	6000	49	6000	49
	20	7008	142	7290	140	7430	140	7570	140	7570	140
1.76	21	7405	-140	7122	-143	6980	-142	6839	-141	6839	-141
	22	6623	124	6879	132	6989	110	7110	121	7110	121
	23	5625	-133	5363	-129	5233	-130	5108	-125	5108	-125
	24	7160	118	7392	114	7509	117	7621	112	7621	112
	25	6285	-119	6050	-116	5935	-115	5820	-115	5820	-115
	26	6439	111	6661	111	6770	109	6880	110	6880	110
	27	6396	-113	6170	-113	6059	-111	5948	-111	5948	-111
	28	7065	113	7289	111	7397	108	7504	107	7504	107
	29	6710	-113	6481	-116	6368	-113	6253	-115	6253	-115

Table VIII. Original Data



Stiffening Ring Breadth = $1\frac{1}{2}$ "			$\tau/c = .35$			Load Decreasing			April 1, 1950		
Load			30030			20010			10015		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5072	- 98	4970	-102	4860	-110	4744	-110	4744	04
	2	5396	-127	5267	-129	5130	-137	4994	-137	4994	04
	3	4359	30	4390	31	4418	28	4404	28	4404	07
	4	5060	43	5102	42	5143	41	5230	41	5230	07
	5	4849	- 90	4753	- 96	4650	-103	4546	-103	4546	06
	6	4700	-104	4596	-104	4481	-115	4370	-115	4370	05
	7	5520	- 15	5502	- 18	5490	- 12	5429	- 12	5429	08
	8	5198	08	5200	02	5204	04	5256	04	5256	07
	9	5722	-100	5620	-102	5509	-111	5401	-111	5401	01
	10	5298	- 96	5200	- 98	5090	-110	4978	-110	4978	07
1.82 ↓	11	6286	68	6364	78	6444	80	6485	80	6485	05
	12	6964	79	7037	73	7111	74	7236	74	7236	09
	13	7103	- 99	7000	-103	6897	-103	6789	-103	6789	04
	14	7282	-108	7176	-106	7070	-106	6965	-106	6965	05
	15	7310	- 21	7290	- 20	7273	- 17	7260	- 17	7260	02
	16	6755	-145	6610	-145	6465	-145	6312	-145	6312	02
	17	6378	-166	6210	-168	6033	-177	5854	-177	5854	04
	18	6510	-118	6390	-120	6259	-131	6120	-131	6120	00
	19	5962	- 36	5923	- 39	5872	- 51	5820	- 51	5820	05
	20	7443	-127	7310	-133	7163	-147	7010	-147	7010	02
1.76 ↓	21	6980	141	7121	141	7270	149	7411	149	7411	06
	22	6900	-110	6889	-111	6760	-129	6628	-129	6628	05
	23	5232	124	5362	130	5495	133	5630	133	5630	05
	24	7520	-101	7414	-106	7291	-123	7165	-123	7165	05
	25	5934	114	6050	116	6170	120	6291	120	6291	06
	26	6785	- 95	6682	-103	6566	-116	6441	-116	6441	02
	27	6057	109	6170	113	6285	115	6401	115	6401	05
	28	7410	- 94	7310	-100	7191	-119	7070	-119	7070	05
	29	6367	114	6480	113	6599	119	6718	119	6718	08

Table VIII. Original Data





Stiffening Ring Breadth = 1 1/2"				$\tau/6 = .5$		Load Increasing		April 1, 1950	
Load		0		11140		22010		43950	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	4750	4860	4967	107	5072	105	5181	109
	2	4999	5140	5280	140	5420	140	5561	141
	3	4410	4434	4400	-34	4360	-40	4324	-36
	4	5233	5120	5070	-113	5024	-46	4978	-46
	5	4550	4649	4748	99	4847	99	4947	100
	6	4371	4490	4603	119	4718	115	4837	115
	7	5432	5524	5543	92	5562	19	5582	20
	8	5260	5192	5192	-68	5191	-1	5192	1
	9	5407	5510	5620	103	5732	110	5845	113
	10	4980	5100	5210	120	5318	110	5429	111
1.82 ↓	11	6485	6447	6355	-38	6264	-92	6173	-91
	12	7240	7191	7008	-49	6922	-183	6837	-85
	13	6798	6932	7058	134	7182	126	7310	128
	14	6970	7096	7226	126	7356	130	7488	132
	15	7264	7286	7311	22	7336	25	7362	26
	16	6318	6510	6688	192	6865	178	7045	180
	17	5860	6070	6270	210	6472	200	6676	204
	18	6126	6264	6398	138	6530	134	6666	136
	19	5823	5858	5893	35	5930	35	5963	33
	20	7010	7132	7250	122	7366	118	7484	118
1.76 ↓	21	7413	7292	7171	-121	7052	-121	6930	-122
	22	6625	6723	6817	98	6910	94	7003	93
	23	5635	5528	5424	-107	5321	-104	5218	-103
	24	7161	7250	7332	89	7417	82	7501	84
	25	6294	6203	6117	-91	6030	-86	5941	-89
	26	6443	6528	6606	85	6684	78	6763	79
	27	6406	6322	6240	-84	6156	-82	6070	-86
	28	7067	7152	7229	85	7306	77	7383	77
	29	6720	6633	6550	-87	6467	-83	6382	-85

Table VIII. Original Data





Stiffening Ring Breadth = 1 1/2"				Load Decreasing				April 1, 1950	
Gage Factor	Gage No.	33015		22090		11030		0	
		Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	From Original Reading
1.80 ↓	1	5080	-101	4975	-105	4867	-108	4750	00
	2	5420	-141	5283	-137	5143	-140	4998	- 01
	3	4370	46	4405	35	4440	35	4411	01
	4	5020	42	5071	51	5122	51	5236	03
	5	4852	- 95	4756	- 96	4656	-100	4550	00
	6	4720	-113	4608	-112	4492	-116	4372	01
	7	5568	- 14	5548	- 20	5525	- 23	5435	03
	8	5188	- 4	5190	2	5193	3	5263	03
	9	5736	-109	5627	-109	5513	-114	5406	- 01
1.82 ↓	10	5323	-106	5217	-106	5108	-109	4982	02
	11	6260	- 87	6352	- 92	6446	- 94	6487	02
	12	6924	87	7009	85	7096	87	7244	04
	13	7188	-122	7060	-128	6932	-128	6798	00
	14	7354	-134	7225	-129	7095	-130	6970	00
	15	7333	- 29	7308	- 25	7283	- 25	7264	00
	16	6864	-181	6687	-177	6507	-180	6320	02
	17	6476	-200	6277	-199	6072	-205	5860	00
	18	6538	-128	6408	-130	6273	-135	6126	00
1.76 ↓	19	5935	- 28	5903	- 32	5870	- 33	5826	03
	20	7374	-110	7262	-112	7143	-119	7013	03
	21	7050	120	7170	120	7294	124	7417	04
	22	6919	- 84	6830	- 89	6735	- 95	6627	02
	23	5320	102	5423	103	5528	105	5650	01
	24	7426	- 75	7348	- 78	7263	- 85	7163	02
	25	6029	88	6117	88	6205	88	6299	05
	26	6693	- 70	6620	- 73	6540	- 80	6447	04
	27	6152	82	6238	86	6323	85	6408	02
	28	7315	- 68	7243	- 72	7165	- 78	7070	03
	29	6465	83	6550	85	6634	84	6722	02

Table VIII. Original Data.



Stiffening Ring Breadth = $1\frac{1}{2}$ "		Pure Bending			Load Increasing			April 1, 1950	
Load	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	4743	99	4938	96	5023	85	5120	97
	2	4999	93	5183	91	5272	89	5370	98
	3	4391	7	4401	3	4408	7	4420	12
	4	5229	- 2	5218	- 9	5202	- 16	5191	- 11
	5	4542	96	4728	90	4815	87	4904	89
	6	4368	83	4530	79	4604	74	4688	84
	7	5417	- 4	5408	- 5	5401	- 7	5409	8
	8	5254	- 9	5230	- 15	5210	- 20	5188	- 22
	9	5403	81	5560	76	5630	70	5705	75
	10	4977	73	5120	70	5188	68	5260	72
1.82 ↓	11	6478	2	6485	5	5490	5	6504	14
	12	7234	- 17	7195	- 22	7170	- 25	7138	- 32
	13	6784	- 6	6766	- 12	6755	- 11	6740	- 15
	14	6962	4	6974	6	6982	8	6992	10
	15	7250	3	7256	3	7256	0	7254	- 2
	16	6307	- 4	6301	- 3	6296	- 5	6292	- 4
	17	5853	29	5910	28	5928	18	5960	32
	18	6122	81	6282	79	6350	68	6434	84
	19	5823	87	5993	83	6067	74	6155	88
	20	7020	239	7493	234	7722	229	7952	235
1.76 ↓	21	7393	-241	6915	-237	6680	-235	6442	-238
	22	6625	237	7099	237	7332	233	7568	236
	23	5610	-247	5120	-243	4875	-245	4633	-242
	24	7162	249	7659	248	7901	242	8144	243
	25	6272	-245	5784	-243	5543	-241	5300	-243
	26	6498		6921		7173	252	7417	244
	27	6381	-246	5890	-245	5647	-243	5402	-245
	28	7068	242	7551	241	7792	241	8032	240
	29	6693	-249	6195	-249	5950	-245	5705	-245

Table VIII. Original Data





Stiffening Ring Breadth = $1\frac{1}{2}$ "				Pure Bending			Load Decreasing			April 1, 1950	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	22010			11080			Indicator Reading	From Original Reading
				Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$		
1.80 ↓	1	5050	- 70	4962	- 88	4860	- 102	4753	- 102	4753	10
	2	5292	- 78	5205	- 87	5106	- 99	5008	- 99	5008	09
	3	4411	- 9	4410	- 1	4407	- 3	4408	- 3	4408	17
	4	5213	- 22	5228	- 15	5234	- 6	5243	- 6	5243	14
	5	4837	- 67	4753	- 84	4657	- 96	4557	- 96	4557	15
	6	4622	- 66	4550	- 72	4464	- 86	4380	- 86	4380	12
	7	5405	- 4	5411	- 6	5420	- 9	5433	- 9	5433	16
	8	5217	- 29	5238	- 21	5253	- 15	5269	- 15	5269	15
	9	5650	- 55	5583	- 67	5500	- 83	5417	- 83	5417	14
1.82 ↓	10	5203	- 57	5140	- 63	5064	- 76	4989	- 76	4989	12
	11	6487	- 17	6481	- 6	6485	- 4	6490	- 4	6490	12
	12	7171	- 33	7200	- 29	7225	- 25	7248	- 25	7248	14
	13	6765	- 25	6780	- 15	6792	- 12	6800	- 12	6800	16
	14	6988	- 4	6983	- 5	6980	- 3	6975	- 3	6975	13
	15	7255	- 1	7256	- 1	7261	- 5	7262	- 5	7262	12
	16	6300	- 8	6308	- 8	6315	- 7	6320	- 7	6320	13
	17	5946	- 14	5923	- 23	5894	- 29	5861	- 29	5861	08
	18	6380	- 54	6309	- 71	6220	- 89	6130	- 89	6130	08
1.76 ↓	19	6094	- 61	6019	- 75	5928	- 91	5832	- 91	5832	09
	20	7750	- 207	7524	- 226	7278	- 246	7030	- 246	7030	10
	21	6673	- 231	6915	- 242	7160	- 245	7410	- 245	7410	17
	22	7360	- 208	7131	- 229	6886	- 245	6632	- 245	6632	07
	23	4872	- 239	5120	- 248	5372	- 252	5628	- 252	5628	18
	24	7930	- 214	7693	- 237	7435	- 258	7170	- 258	7170	08
	25	5540	- 240	5787	- 247	6034	- 247	6289	- 247	6289	17
	26	7200	- 217	6968	- 232	6713	- 255	6451	- 255	6451	18
	27	5642	- 240	5891	- 249	6142	- 251	6399	- 251	6399	07
	28	7820	- 212	7587	- 233	7332	- 255	7075	- 255	7075	17
	29	5948	- 243	6200	- 252	6451	- 251	6710	- 251	6710	17

Table VIII. Original Data



















Stiffening Ring Breadth = 3/4"			$\tau/6 = .35$			Load Decreasing			April 4, 1950		
Load			29910			20000			10040		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5272	-101	5170	-102	5058	-112	4940	-112	4940	00
	2	5601	-133	5473	-128	5333	-140	5191	-140	5191	- 01
	3	4562	32	4593	31	4623	30	4630	30	4630	- 08
	4	5275	45	5320	45	5368	48	5440	48	5440	05
	5	5129	-113	5011	-118	4882	-129	4751	-129	4751	- 01
	6	4933	-120	4816	-117	4690	-126	4560	-126	4560	00
	7	5690	- 8	5682	- 8	5677	- 5	5640	- 5	5640	00
	8	5413	9	5423	10	5433	10	5473	10	5473	03
	9	5980	-118	5861	-119	5731	-130	5602	-130	5602	- 01
	10	5558	-115	5445	-113	5322	-123	5198	-123	5198	00
1.80 ↓	11										
	12	7056	75	7130	74	7205	75	7317	75	7317	07
	13	7130	- 91	7040	- 90	6950	- 90	6861	- 90	6861	01
	14	7340	-110	7234	-106	7128	-106	7020	-106	7020	- 02
	15	7405	- 27	7382	- 23	7363	- 19	7348	- 19	7348	03
	16	6915	-178	6740	-175	6563	-177	6382	-177	6382	- 01
	17	6545	-213	6335	-210	6117	-218	5897	-218	5897	- 03
	18	6739	-153	6582	-157	6411	-171	6233	-171	6233	- 01
	19	6023	- 47	5973	- 50	5910	- 63	5842	- 63	5842	- 01
	20	7501	-130	7371	-130	7226	-145	7075	-145	7075	- 03
1.76 ↓	21	6804	141	6945	141	7089	144	7230	144	7230	10
	22	6804	-107	6695	-109	6571	-124	6440	-124	6440	00
	23	5047	127	5170	123	5300	130	5430	130	5430	08
	24	7312	-100	7211	-101	7094	-117	6970	-117	6970	- 01
	25	5760	111	5870	110	5985	115	6101	115	6101	07
	26	6583	- 96	6488	- 95	6373	-115	6255	-115	6255	02
	27	5873	106	5982	109	6095	113	6205	113	6205	05
	28	7201	- 96	7107	- 94	6994	-113	6875	-113	6875	- 02
	29	6182	110	6292	110	6405	113	6519	113	6519	06

Table IX. Original Data





Stiffening Ring Breadth = 3/4"				$\pi/6 = .5$		Load Increasing		April 4, 1950			
Load		0		10910		21990		32900		39995	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
1.80 ↓	1	4940	109	5151	102	5254	103	5321	103	5321	67
	2	5190	146	5479	143	5618	139	5705	139	5705	87
	3	4630	8	4600	- 38	4560	- 40	4533	- 40	4533	- 27
	4	5440	- 98	5290	- 52	5240	- 50	5209	- 50	5209	- 31
	5	4752	128	5005	125	5127	122	5205	122	5205	78
	6	4559	132	4823	132	4950	127	5033	127	5033	83
	7	5640	63	5715	12	5722	7	5728	7	5728	6
	8	5473	- 53	5413	- 7	5409	- 4	5403	- 4	5403	6
	9	5604	132	5870	134	6000	130	6085	130	6085	85
	10	5197	133	5457	127	5581	124	5661	124	5661	80
1.82 ↓	11										
	12	7318	-137	7109	- 72	7015	- 94	6962	- 94	6962	- 53
	13	6865	115	7100	120	7203	103	7276	103	7276	73
	14	7020	131	7297	146	7412	115	7495	115	7495	83
	15	7349	29	7420	42	7439	19	7457	19	7457	18
	16	6384	226	6840	230	7049	209	7185	209	7185	136
	17	5900	252	6412	260	6661	249	6822	249	6822	161
	18	6239	181	6600	180	6770	170	6880	170	6880	110
	19	5842	47	5928	39	5970	42	6000	42	6000	30
	20	7073	121	7309	115	7420	111	7493	111	7493	73
1.76 ↓	21	7227	-118	6990	-119	6870	-120	6795	-120	6795	- 75
	22	6440	92	6622	90	6711	89	6770	89	6770	59
	23	5430	-100	5230	-100	5131	- 99	5068	- 99	5068	- 63
	24	6971	80	7130	79	7206	76	7258	76	7258	52
	25	6101	- 83	5936	- 82	5852	- 84	5800	- 84	5800	- 52
	26	6253	78	6405	74	5479	74	6522	74	6522	43
	27	6208	- 79	6050	- 79	5972	- 78	5921	- 78	5921	- 51
	28	6874	80	7029	75	7100	71	7142	71	7142	42
	29	6520	- 80	6360	- 80	6280	- 80	6230	- 80	6230	- 50

Table IX. Original Data



Stiffening Ring Breadth = 3/4"			$\tau/\delta = .5$		Load Decreasing			April 4, 1950	
Load		32920		22080		11060		0	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5259	- 62	5158	-101	5050	-108	4940	00
	2	5614	- 91	5479	-135	5338	-141	5189	- 01
	3	4566	33	4601	35	4640	39	4630	00
	4	5235	26	5290	55	5343	53	5443	03
	5	5130	- 75	5010	-120	4882	-128	4750	- 02
	6	4950	- 83	4821	-129	4691	-130	4558	- 01
	7	5729	1	5717	- 12	5703	- 14	5640	00
	8	5400	3	5410	10	5419	9	5477	04
	9	6000	- 85	5872	-128	5739	-133	5601	- 03
	10	5581	- 80	5460	-121	5330	-130	5193	- 04
1.82 ↓	11								
	12	7014	52	7098	84	7181	83	7322	04
	13	7202	- 74	7090	-112	6978	-112	6863	- 02
	14	7408	- 87	7277	-131	7148	-129	7019	- 01
	15	7432	- 25	7400	- 32	7372	- 28	7350	01
	16	7040	-145	6827	-213	6608	-219	6381	- 03
	17	6660	-162	6410	-250	6151	-259	5894	- 06
	18	6770	-110	6600	-170	6424	-176	6240	01
	19	5975	- 25	5938	- 37	5895	- 43	5843	01
	20	7424	- 69	7314	-110	7200	-114	7072	- 01
1.76 ↓	21	6870	75	6990	120	7110	120	7230	03
	22	6718	- 52	6632	- 86	6541	- 91	6440	00
	23	5131	63	5230	99	5330	100	5434	04
	24	7210	- 48	7140	- 70	7060	- 80	6970	- 01
	25	5852	52	5935	83	6020	85	6103	02
	26	6481	- 41	6415	- 66	6342	- 73	6258	05
	27	5971	50	6050	79	6130	80	6210	02
	28	7101	- 41	7037	- 64	6963	- 74	6875	01
	29	6280	50	6360	80	6441	81	6522	02

Table IX. Original Data





Stiffening Ring Breadth = 3/4"		Pure Bending			Load Increasing			April 4, 1950	
Load	Gage	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>	Indicator Reading	Strain Increment x10 <sup>6</sup>
	No.	0	10940	21900	32920	43980			
1.80 ↓	1	4940	5048	5151	5257	5360	103	5360	103
	2	5188	5290	5388	5487	5584	97	5584	97
	3	4628	4630	4625	4623	4621	- 2	4621	- 2
	4	5438	5420	5410	5400	5383	- 10	5383	- 17
	5	4750	4848	4947	5042	5138	95	5138	96
	6	4558	4645	4728	4810	4895	82	4895	85
	7	5634	5634	5622	5612	5604	- 10	5604	- 8
	8	5470	5442	5430	5410	5390	- 20	5390	- 20
	9	5600	5668	5736	5802	5870	66	5870	68
	10	5191	5266	5337	5407	5480	70	5480	73
1.82 ↓	11								
	12	7310	7277	7260	7238	7212	- 17	7212	- 26
	13	6852	6835	6822	6808	6790	- 13	6790	- 18
	14	7013	7018	7019	7018	7020	1	7020	2
	15	7336	7335	7338	7337	7334	3	7334	3
	16	6370	6360	6351	6340	6329	- 9	6329	- 11
	17	5882	5910	5936	5961	5989	26	5989	28
	18	6247	6344	6440	6534	6630	96	6630	96
	19	5838	5939	6042	6142	6247	103	6247	105
	20	7077	7310	7542	7773	8001	232	8001	228
1.76 ↓	21	7226	6990	6754	6520	6287	-236	6287	-233
	22	6460	6697	6929	7160	7390	232	7390	230
	23	5430	5184	4942	4700	4460	-246	4460	-240
	24	6992	7236	7480	7722	7962	244	7962	240
	25	6099	5857	5618	5378	5140	-242	5140	-238
	26	6277	6519	6760	6998	7238	241	7238	240
	27	6202	5959	5717	5473	5232	-243	5232	-241
	28	6898	7134	7373	7610	7848	236	7848	238
	29	6518	6270	6027	5780	5536	-248	5536	-244

Table IX. Original Data





Stiffening Ring Breadth = 3/4"			Pure Bending			Load Decreasing			April 4, 1950		
Load			32960			20600			11060		
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	5274	- 86	5158	-116	5056	-102	4940	-102	4940	00
	2	5500	- 84	5390	-110	5298	- 92	5187	- 92	5187	- 01
	3	4620	- 1	4622	2	4628	6	4628	6	4628	00
	4	5400	17	5412	12	5420	8	5438	8	5438	00
	5	5060	- 78	4952	-108	4859	- 93	4750	- 93	4750	00
	6	4822	- 73	4729	- 93	4650	- 79	4556	- 79	4556	- 02
	7	5608	4	5620	12	5631	11	5637	11	5637	03
	8	5412	22	5430	18	5443	13	5470	13	5470	00
	9	5820	- 50	5743	- 77	5678	- 65	5602	- 65	5602	02
	10	5419	- 61	5340	- 79	5271	- 69	5190	- 69	5190	- 01
1.82 ↓	11										
	12	7235	23	7256	21	7274	18	7310	18	7310	00
	13	6810	20	6827	17	6840	13	6857	13	6857	05
	14	7018	- 2	7018	0	7017	- 1	7012	- 1	7012	- 01
	15	7330	- 4	7330	0	7333	3	7337	3	7337	01
	16	6340	11	6351	11	6360	9	6370	9	6370	00
	17	5972	- 17	5943	- 29	5916	- 27	5881	- 27	5881	01
	18	6561	- 69	6462	- 99	6375	- 87	6315	- 87	6315	- 68
	19	6166	- 81	6052	-114	5952	-100	5835	-100	5835	- 03
	20	7790	-211	7530	-260	7318	-212	7070	-212	7070	- 07
1.76 ↓	21	6515	228	6780	265	6990	210	7232	210	7232	06
	22	7178	-212	6919	-259	6705	-214	6454	-214	6454	- 06
	23	4699	239	4970	271	5186	216	5435	216	5435	05
	24	7743	-219	7471	-272	7248	-223	6987	-223	6987	- 05
	25	5376	236	5646	270	5858	212	6105	212	6105	06
	26	7020	-218	6752	-268	6531	-221	6272	-221	6272	- 05
	27	5470	238	5743	273	5960	217	6210	217	6210	08
	28	7630	-218	7365	-265	7145	-220	6890	-220	6890	- 08
	29	5778	242	6053	275	6270	217	6523	217	6523	05

Table IX. Original Data



Stiffening Ring Breadth = 7/16" $\frac{1}{6} = .2$				Load Incr-Decreasing		April 5, 1950	
Load		0		19040		37980	
Gage Factor	Gage No.	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	From Original Reading
1.80 ↓	1	4952	5209	5456	257	4950	- 02
	2	5166	5439	5715	273	5162	- 04
	3	4611	4562	4503	- 49	4609	- 02
	4	5440	5351	5272	- 89	5438	- 02
	5	4761	5035	5299	274	4758	- 03
	6	4551	4847	5143	296	4547	- 04
	7	5622	5628	5618	6	5622	00
	8						
1.82 ↓	9	5618	5881	6131	263	5615	- 03
	10	5190	5453	5723	263	5188	- 02
	11						
	12	7280	7174	7088	-106	7280	00
	13	6850	6996	7135	146	6849	- 01
	14	7000	7130	7258	130	6998	- 02
	15	7357	7381	7409	24	7353	- 04
	16	6430	6713	6998	183	6427	- 03
1.76 ↓	17	5867	6282	6698	315	5863	- 04
	18	6152	6523	6883	371	6150	- 02
	19	5853	6033	6211	180	5851	- 02
	20	7060	7440	7812	380	7057	- 03
	21	7162	6785	6408	-377	7167	05
	22	6397	6742	7080	345	6397	00
	23	5380	5018	4663	-362	5384	04
	24	6934	7272	7607	338	6933	- 01
	25	6060	5723	5392	-337	6064	04
	26	6259	6590	6915	331	6260	01
	27	6194	5864	5537	-330	6200	06
	28	6871	7198	7521	327	6870	- 01
	29	6497	6160	5828	-337	6500	03

Table X. Original Data





Stiffening Ring Breadth = 7/16"		σ = .35		Load Incr-Decreasing		April 7, 1950	
Load	Gage	Indicator	Strain	Indicator	Strain	Indicator	From
	No.	Reading	Increment x10 <sup>6</sup>	Reading	Increment x10 <sup>6</sup>	Reading	Original Reading
1.80	1	4950	5182	5370	188	4950	00
↓	2	5163	5422	5645	223	5160	- 03
	3	4610	4560	4501	- 59	4610	00
	4	5435	5329	5252	106	5437	02
	5	4759	5025	5240	266	4758	- 01
	6	4549	4851	5109	302	4545	- 04
	7	5623	5651	5651	28	5623	00
	8						
	9	5618	5890	6114	272	5613	- 05
1.82	10	5191	5480	5730	289	5288	- 03
↓	11						
	12	7275	7140	7050	-135	7277	02
	13	6850	7050	7220	200	6849	- 01
	14	7000	7181	7332	181	7000	00
	15	7356	7390	7430	34	7354	- 02
	16	6431	6830	7168	399	6430	- 01
	17	5870	6390	6840	520	5869	- 01
	18	6152	6540	6860	390	6151	- 01
	19	5852	5980	6087	128	5853	01
1.76	20	7056	7339	7575	283	7055	- 01
↓	21	7170	6889	6649	-281	7171	01
	22	6395	6630	6831	235	6395	00
	23	5388	5132	4924	-256	5390	02
	24	6932	7150	7337	218	6933	01
	25	6068	5846	5660	-222	6070	02
	26	6260	6470	6648	210	6260	00
	27	6202	5990	5810	-212	6205	03
	28	6870	7081	7258	211	6872	02
	29	6503	6285	6100	-218	6508	05

Table X. Original Data



Stiffening Ring Breadth = 7/16"		$\sigma/\delta = .5$		Load Incr-Decreasing		April 6, 1950	
Load	Gage	Indicator	Strain	Indicator	Strain	Indicator	From
Gage	No.	Reading	Increment	Reading	Increment	Reading	Original
Factor			x106		x106		Reading
1.80	1	4949	214	5312	149	4949	00
	2	5161	249	5590	180	5162	01
	3	4594	- 51	4490	- 53	4599	05
	4	5432	-114	5253	- 65	5438	06
	5	4756	257	5192	179	4757	01
	6	4544	303	5065	218	4545	01
	7	5618	39	5660	3	5620	02
	8						
	9	5613	277	6082	192	5612	- 01
	10	5188	301	5709	220	5188	00
1.82	11						
	12	7267	-140	7055	- 72	7271	04
	13	6843	-234	7242	-165	6845	02
	14	6998	209	7352	145	6999	01
	15	7347	47	7438	44	7349	02
	16	6430	460	7223	333	6430	00
	17	5887	580	6885	418	5885	- 02
	18	6166	394	6833	273	6166	00
	19	5858	98	6023	67	5860	02
1.76	20	7050	224	7433	159	7052	02
	21	7163	-216	6788	-159	7168	05
	22	6387	173	6680	120	6390	03
	23	5390	-181	5080	-129	5393	03
	24	6932	149	7185	104	6935	03
	25	6068	-148	5813	-107	6072	04
	26	6251	140	6490	99	6256	05
	27	6202	-134	5968	-100	6210	08
	28	6868	142	7107	97	6870	02
	29	6502	-140	6260	-102	6508	06

Table X. Original Data



Stiffening Ring Breadth = 7/16"		Pure Bending		Load Incr--Decreasing		April 6, 1950	
Load	Gage	Indicator	Strain	Indicator	Strain	Indicator	From
Factor	No.	Reading	Increment x10 <sup>6</sup>	Reading	Increment x10 <sup>6</sup>	Reading	Original Reading
1.80	1	4949	214	5377	214	4949	00
	2	5161	229	5614	224	5162	01
	3	4589	- 15	4561	- 13	4592	03
	4	5434	- 30	5370	- 34	5434	00
	5	4756	196	5143	191	4757	01
	6	4542	103	4943	98	4541	- 01
	7	5612	- 27	5560	- 25	5614	02
	8						
	9	5610	143	5895	142	5610	00
	10	5183	140	5460	137	5185	02
1.82	11						
	12	7268	- 26	7207	- 35	7270	02
	13	6838	- 28	6777	- 33	6840	02
	14	6990	- 7	6977	- 6	6993	03
	15	7340	5	7340	- 5	7342	02
	16	6419	- 37	6340	- 42	6422	03
	17	5877	56	5989	56	5876	- 01
	18	6160	207	6572	205	6160	00
	19	5856	221	6298	221	5854	- 02
	20	7053	474	7993	466	7051	- 02
	21	7152	-476	6200	-476	7155	03
	22	6392	473	7332	467	6390	- 02
	23	5380	-492	4399	-489	5382	02
	24	6940	492	7920	488	6940	00
	25	6058	-488	5084	-486	6060	02
	26	6262	488	7232	482	6262	00
	27	6193	-491	5212	-490	6197	04
	28	6875	483	7838	480	6873	- 02
	29	6491	-497	5500	-494	6495	04

Table X. Original Data





Stiffening Ring Breadth = 7/16"		$\frac{1}{8} = .2$		Load Increasing		April 25, 1950	
Load		0		9000		37950	
Gage Factor	Gage No.	Indicator Reading		Strain Increment x10 <sup>6</sup>		Indicator Reading	
		0		18020		27000	
1.77	↓	Indicator Reading		Strain Increment x10 <sup>6</sup>		Indicator Reading	
		0		18020		27000	
1A		6964	6943	- 21	- 43	6855	6803
2A		4997	4927	- 70	- 49	4828	4766
3A		5829	5892	63	65	6020	6098
4A		5969	6028	59	50	6125	6188
5A		6742	6696	- 46	- 64	6567	6490
6A		5204	5127	- 77	- 61	5008	4932
7A		6595	6567	- 28	- 65	6440	6365
8A		5370	5440	70	70	5580	5664
9A		5714	5690	- 24	- 57	5580	5512
15		7505	7516	11	13	7542	7557
16		6575	6715	140	136	6988	7152
17		6101	6298	197	200	6697	6938
18		6400	6567	167	167	6900	7102
19		6010	6090	80	83	6255	6357
1.82	↓						
Load Decreasing							
		17940		0		From Original Reading	
1.77	↓						
1A		6900	6970	97		6970	06
2A		4885	5007	119		5007	10
3A		5953	5828	-145		5828	- 01
4A		6072	5970	-116		5970	01
5A		6631	6750	141		6750	08
6A		5072	5216	140		5216	12
7A		6500	6602	135		6602	07
8A		5510	5370	154		5370	00
9A		5633	5720	121		5720	06
15		7519	7503	- 38		7503	- 02
16		6847	6577	-305		6577	02
17		6507	6098	-431		6098	- 03
18		6756	6396	-346		6396	- 04
19		6200	6008	-157		6008	- 02
1.82	↓						

Table XI. Original Data



Stiffening Ring Breadth = 7/16"		$\delta/S = .35$		Load Increasing		April 25, 1950	
Load		0		9150		36015	
Gage Factor	Gage No.	Indicator Reading		Strain Increment $\times 10^6$		Indicator Reading	
		Indicator Reading		Strain Increment $\times 10^6$		Indicator Reading	
1.77 ↓	1A	6970	6943	- 27	- 59	6826	- 58
	2A	5001	4897	-104	- 63	4771	- 63
	3A	5828	5910	82	83	6078	85
	4A	5970	6049	79	62	6175	64
	5A	6749	6683	- 66	- 88	6510	- 85
	6A	5209	5094	-115	- 74	4945	- 75
	7A	6603	6570	- 33	- 79	6413	- 78
	8A	5370	5449	79	81	5613	83
	9A	5720	5693	- 27	- 69	5556	- 68
	15	7503	7516	13	22	7560	22
1.82 ↓	16	6580	6762	182	181	7127	184
	17	6100	6341	241	236	6813	236
	18	6397	6569	172	161	6890	160
	19	6008	6066	58	50	6166	50
Load Decreasing							
18000				0			
1.77 ↓	1A	6887	6870	120		6970	00
	2A	4840	5005	132		5005	04
	3A	5989	5823	-173		5823	- 05
	4A	6105	5968	-135		5968	- 02
	5A	6600	6747	180		6747	- 02
	6A	5024	5217	155		5217	08
	7A	6490	6604	156		6604	01
	8A	5528	5368	-170		5368	- 02
	9A	5623	5725	135		5725	05
	15	7531	7504	- 49		7504	01
1.82 ↓	16	6940	6580	-370		6580	00
	17	6584	6100	-468		6100	00
	18	6741	6393	-316		6393	- 04
	19	6132	6009	- 91		6009	01

Table XI. Original Data





Stiffening Ring Breadth = 7/16"		$\frac{1}{4} = .5$		Load Increasing		April 25, 1950	
Load	Gage Factor	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$	Indicator Reading	Strain Increment $\times 10^6$
		0	9070	18130	27040	34945	
1.77 ↓	1A	6970	6940	6870	- 30	6745	- 57
	2A	5000	4883	4813	- 117	4690	- 60
	3A	5826	5920	6017	94	6198	88
	4A	5969	6053	6123	84	6260	62
	5A	6748	6673	6572	- 75	6383	- 81
	6A	5208	5081	5000	- 127	4845	- 71
	7A	6601	6565	6474	- 36	6312	- 78
	8A	5370	5458	5547	88	5715	77
	9A	5720	5690	5610	- 30	5470	- 66
1.82 ↓	15	7502	7519	7542	17	7593	23
	16	6580	6785	6995	205	7386	185
	17	6100	6360	6623	260	7108	228
	18	6397	6567	6731	170	7033	141
	19	6008	6051	6090	43	6157	29
Load Decreasing							
		18060	0	From Original Reading			
1.77 ↓	1A	6879	134	6970	00		
	2A	4821	131	5008	08		
	3A	6010	- 188	5820	- 06		
	4A	6118	- 142	5960	- 09		
	5A	6580	197	6750	02		
	6A	5003	158	5220	12		
	7A	6479	167	6605	04		
	8A	5541	- 174	5367	- 03		
	9A	5613	143	5720	00		
1.82 ↓	15	7540	- 53	7500	- 02		
	16	6990	- 396	6578	- 02		
	17	6621	- 487	6100	00		
	18	6732	- 301	6390	- 07		
	19	6093	- 64	6006	- 02		

Table XI. Original Data



Stiffening Ring Breadth = 7/16"				Pure Bending			Load Increasing			April 25, 1950		
Load				0			11060			22030		
Gage Factor	Gage No.	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Indicator Reading	Strain Increment x106	Strain Increment x106
1.77 ↓	1A	6980	30	7030	20	7055	25	7088	25	7088	33	33
	2A	5013	- 23	4975	- 15	4957	- 18	4928	- 15	4928	- 29	- 29
	3A	5828	- 13	5797	- 18	5782	- 15	5760	- 15	5760	- 22	- 22
	4A	5976	- 1	5971	- 4	5970	- 1	5971	- 1	5971	1	1
	5A	6761	38	6825	26	6850	25	6895	25	6895	45	45
	6A	5222	- 20	5193	- 9	5180	- 13	5155	- 13	5155	- 25	- 25
	7A	6613	27	6648	8	6662	14	6682	14	6682	20	20
	8A	5371	9	5390	10	5398	8	5404	8	5404	6	6
	9A	5728	20	5757	9	5768	11	5787	11	5787	19	19
1.82 ↓	15	7495	- 5	7488	- 2	7483	- 5	7475	- 5	7475	- 8	- 8
	16	6570	- 27	6518	- 25	6492	- 26	6465	- 26	6465	- 27	- 27
	17	6090	22	6136	24	6160	24	6182	24	6182	22	22
	18	6390	100	6591	101	6691	100	6790	100	6790	99	99
	19	6005	112	6230	113	6341	111	6452	111	6452	111	111
Load Decreasing				0			From Original Reading					
				21900								
1.77 ↓	1A	7030	- 58	6976	- 04							
	2A	4975	47	5013	00							
	3A	5801	41	5830	02							
	4A	5970	- 1	5978	02							
	5A	6814	- 81	6758	- 03							
	6A	5191	36	5223	01							
	7A	6639	- 43	6612	- 01							
	8A	5393	- 11	5371	00							
	9A	5751	- 36	5726	- 02							
1.82 ↓	15	7479	4	7495	00							
	16	6515	50	6570	00							
	17	6148	- 34	6087	- 03							
	18	6618	-172	6386	- 04							
	19	6258	-194	6001	- 04							

Table XI. Original Data





Figure XXV

FIGURE XXV

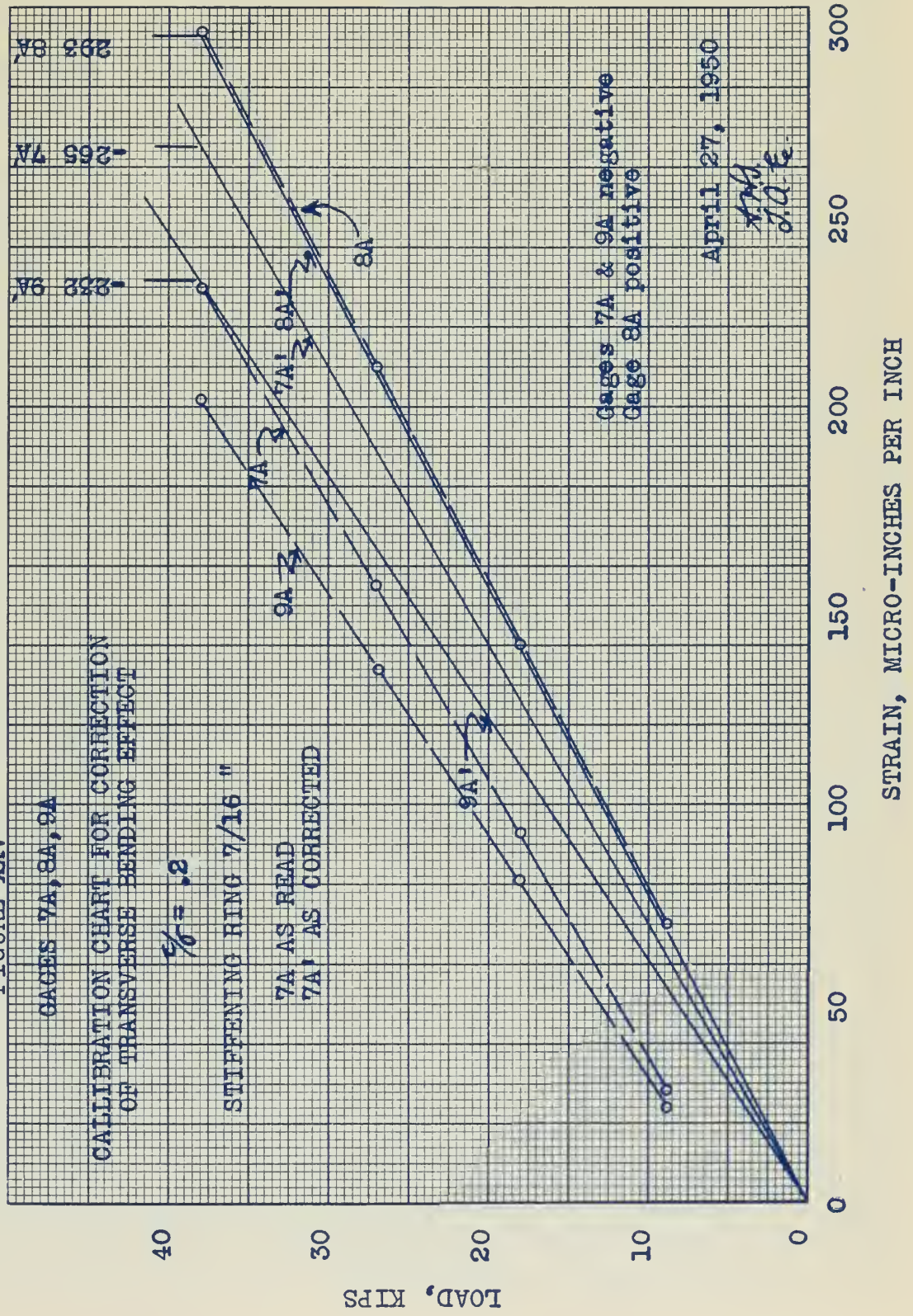






Figure XXVI

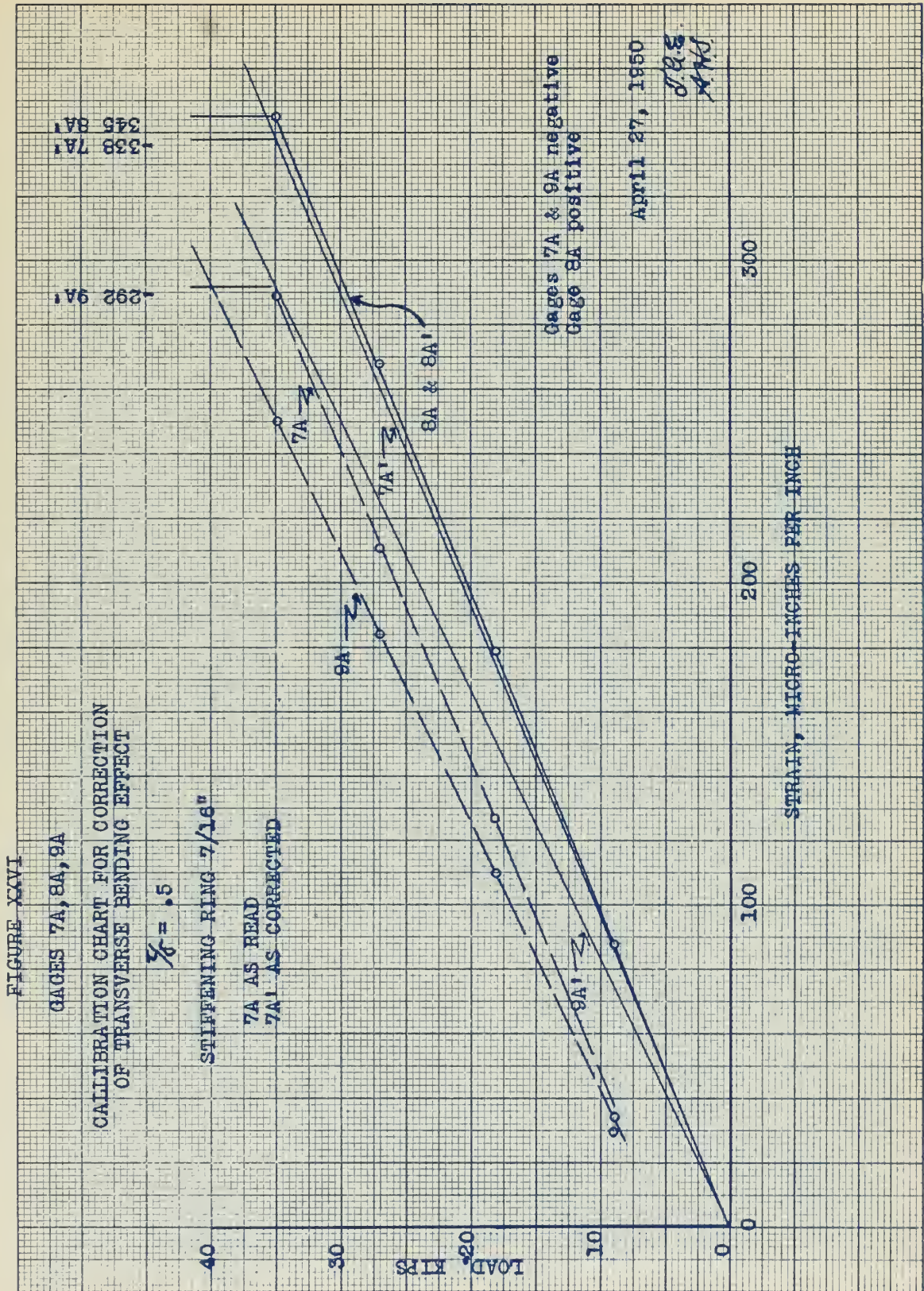






Figure XXVII

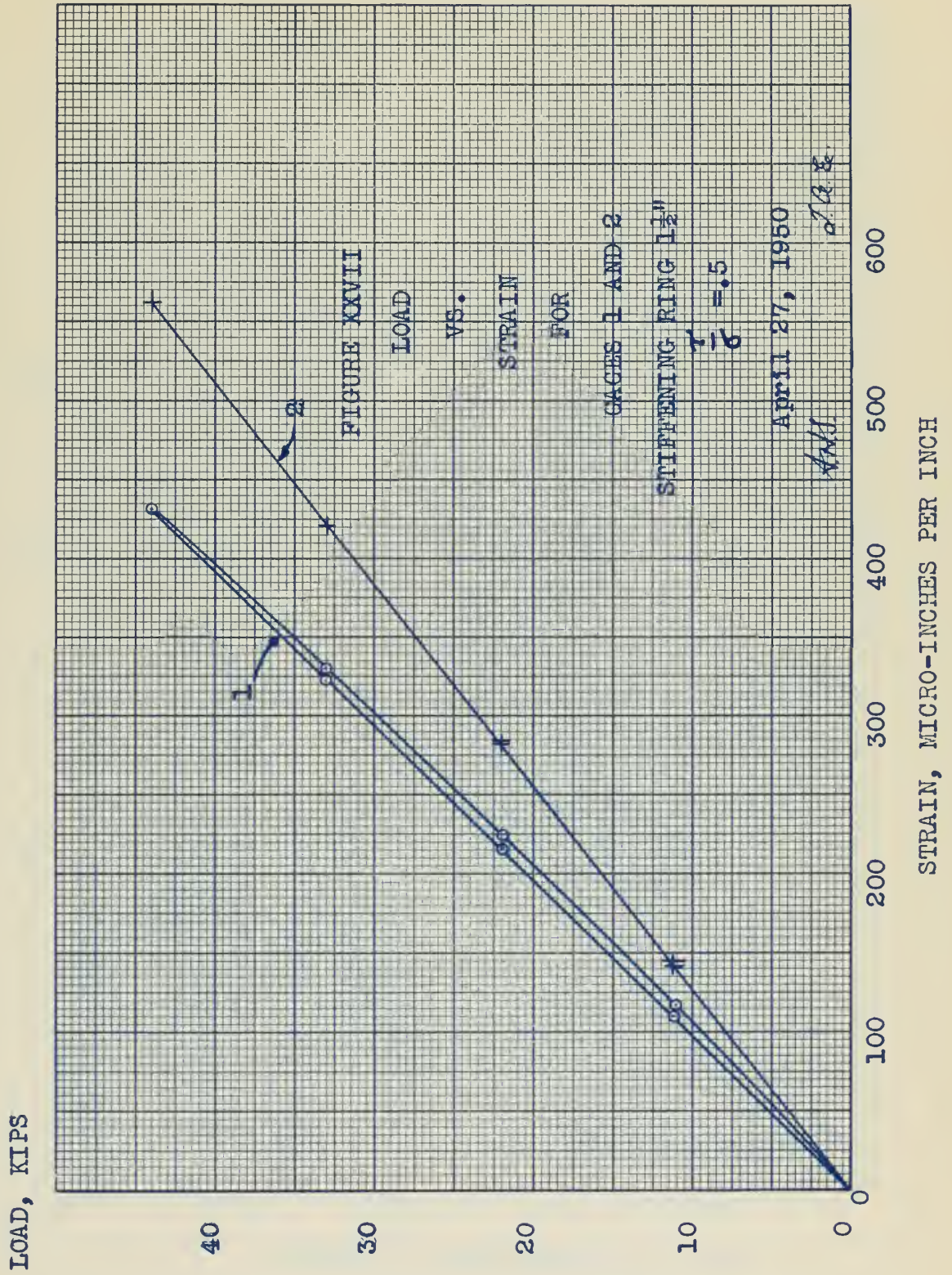






Figure XXVIII

LOAD, KIPS

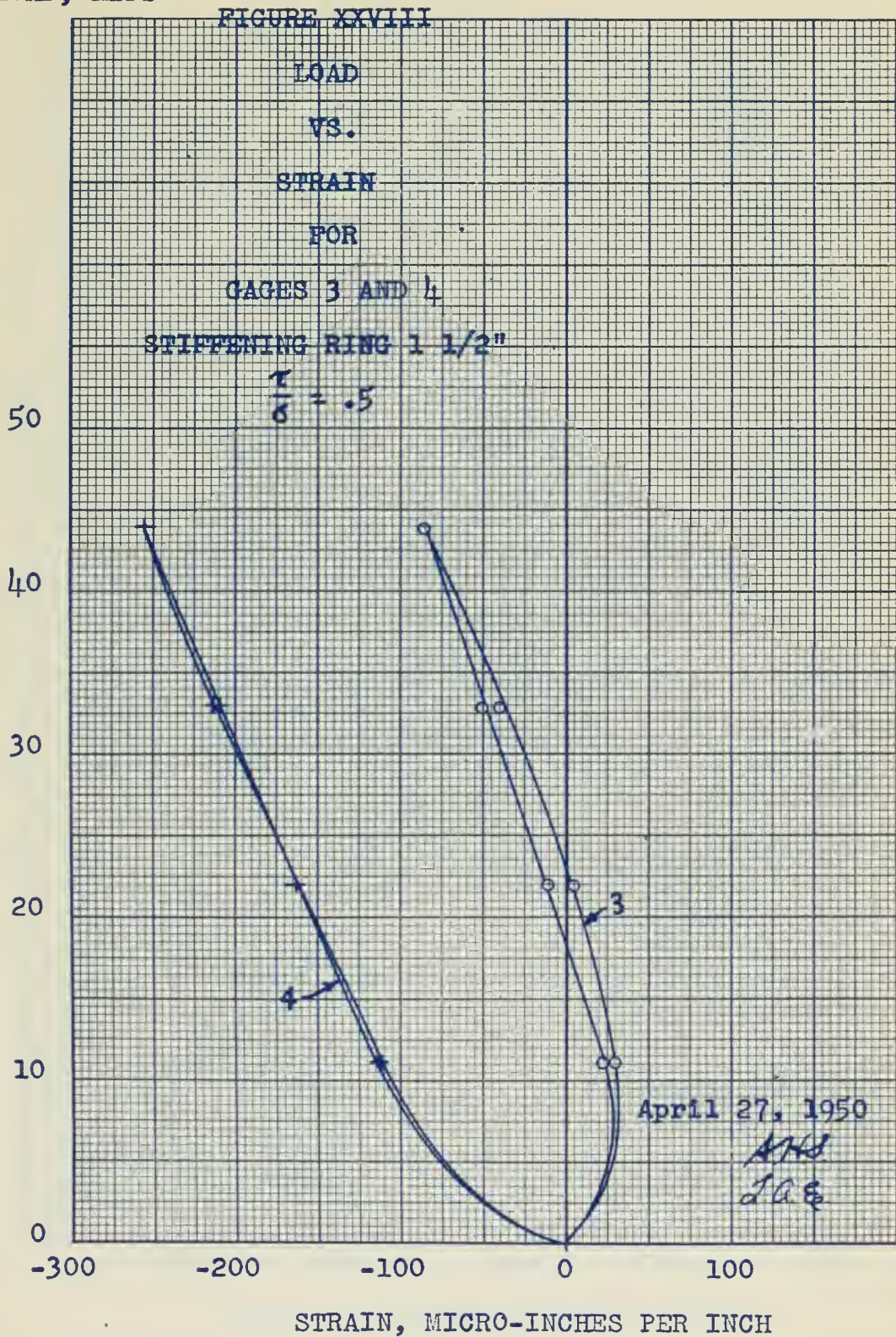






Figure XXIX

LOAD, KIPS

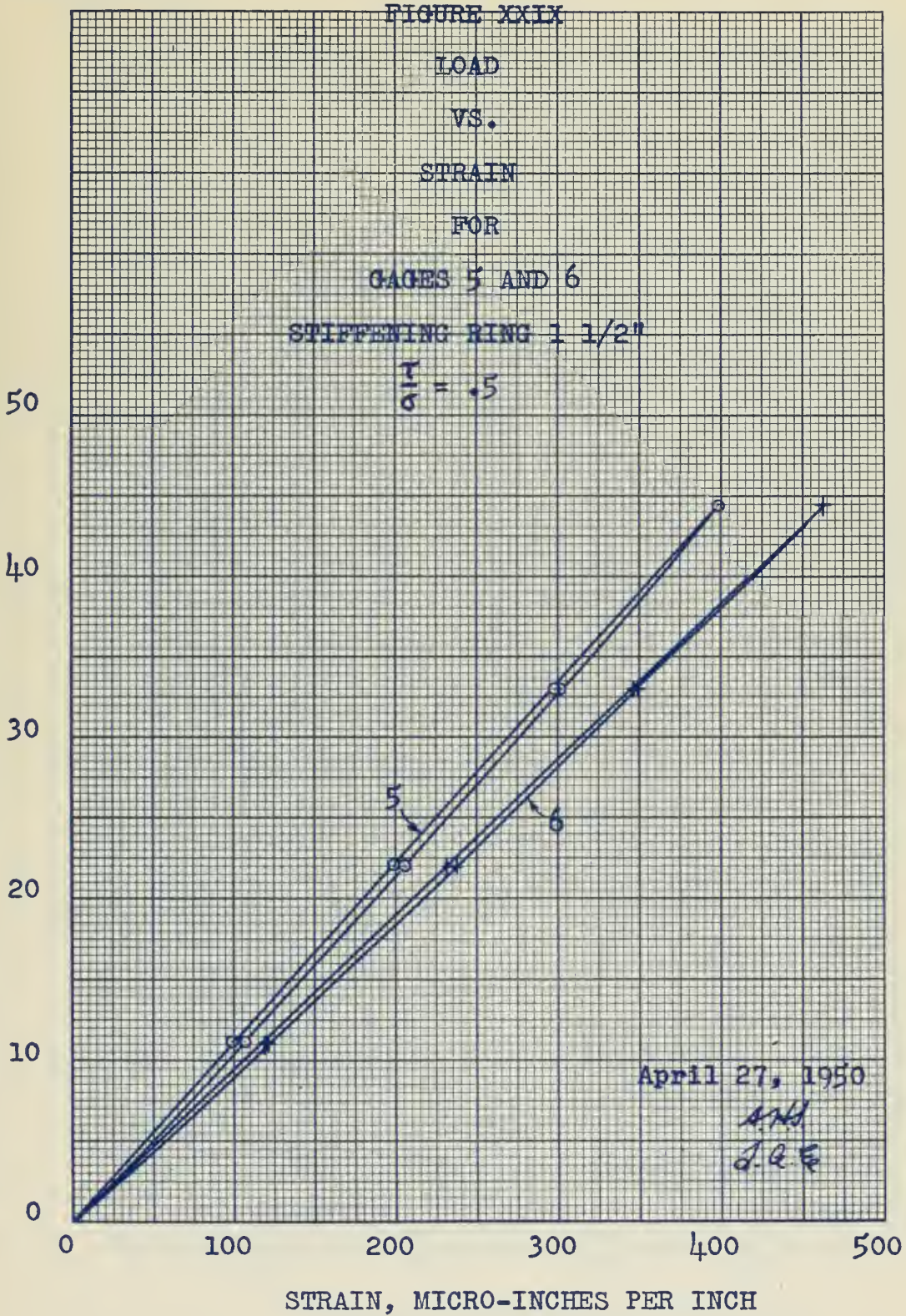






Figure XXX

LOAD, KIPS

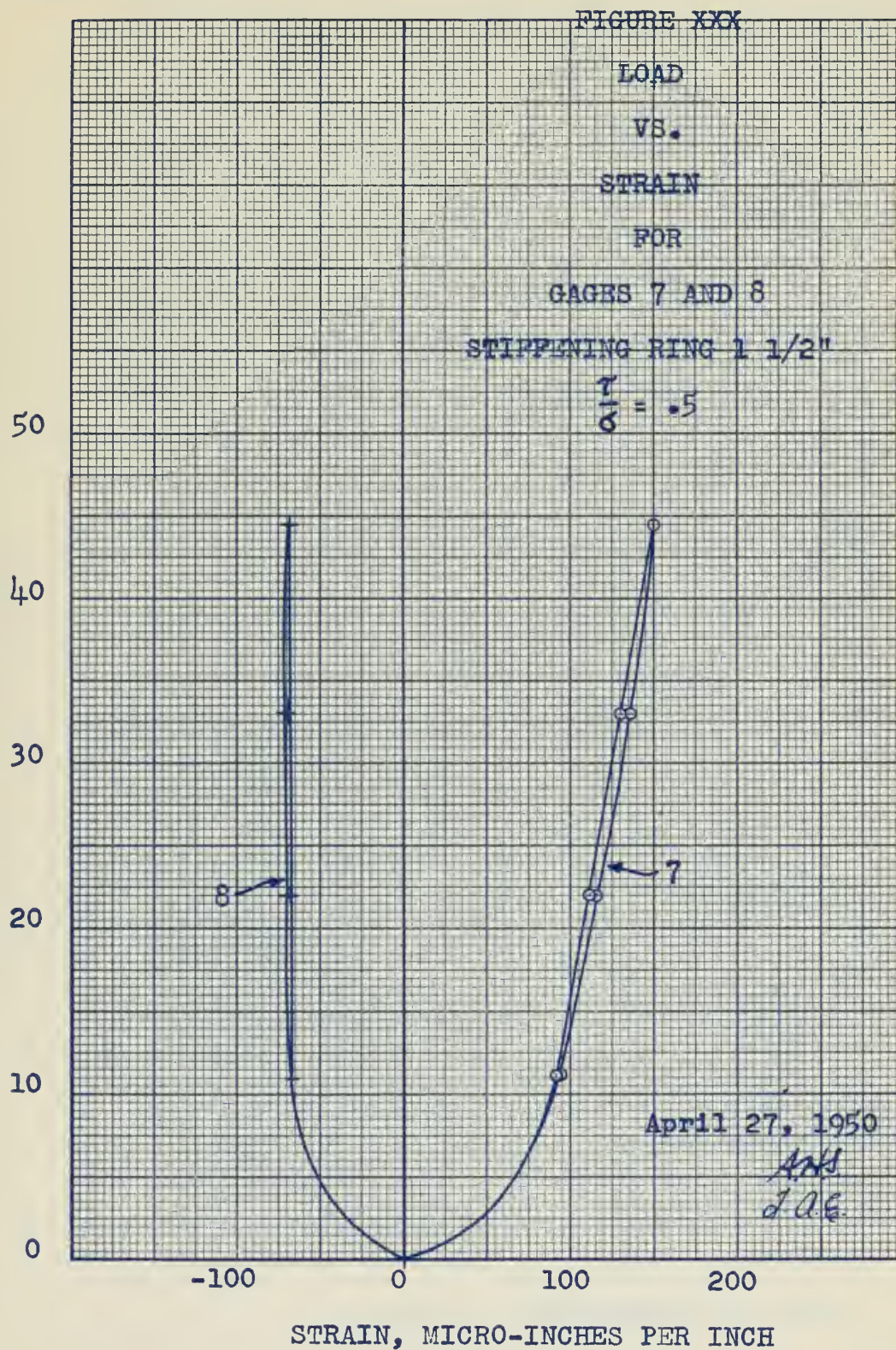






Figure XXXI

LOAD, KIPS

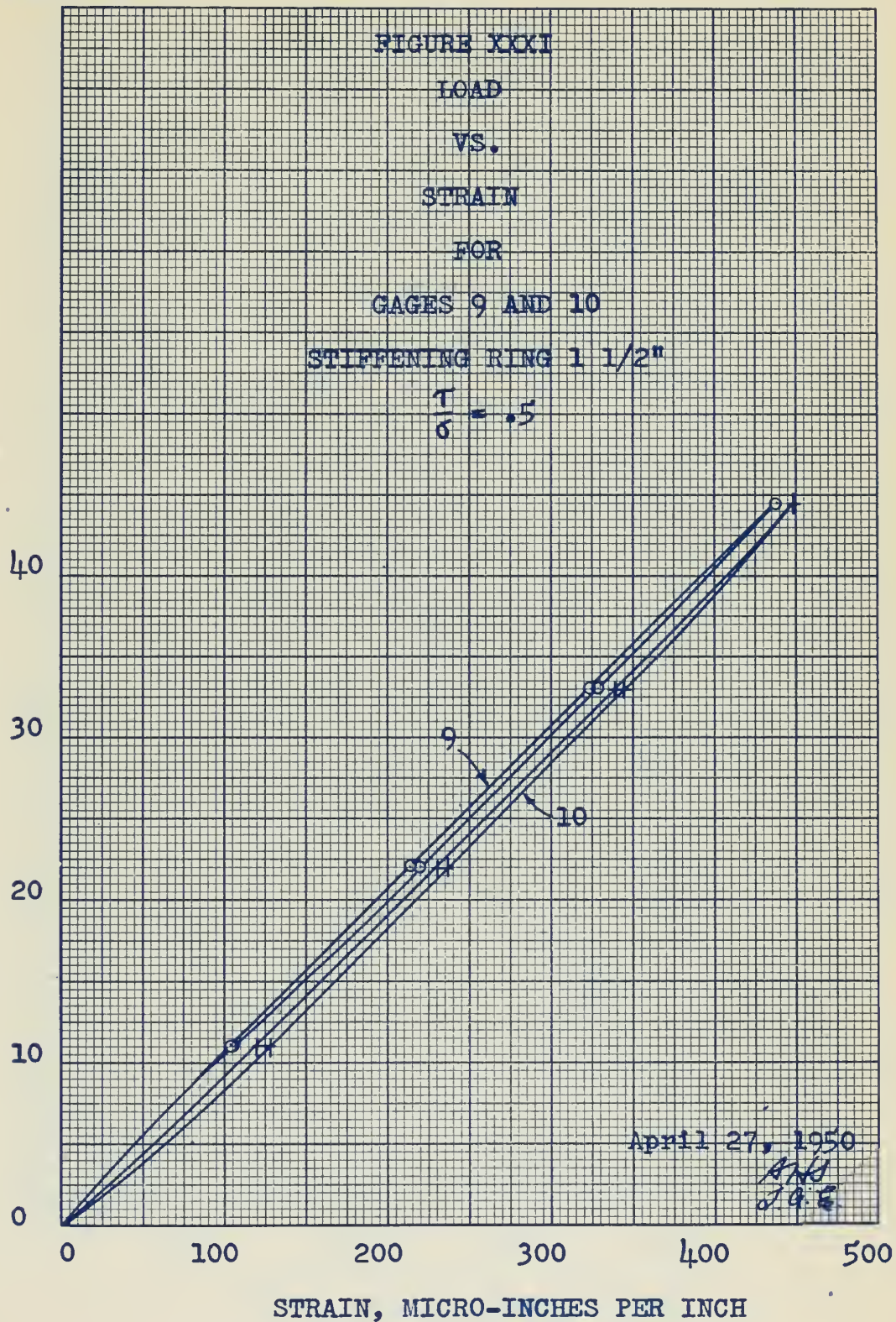






Figure XXXII

LOAD, KIPS

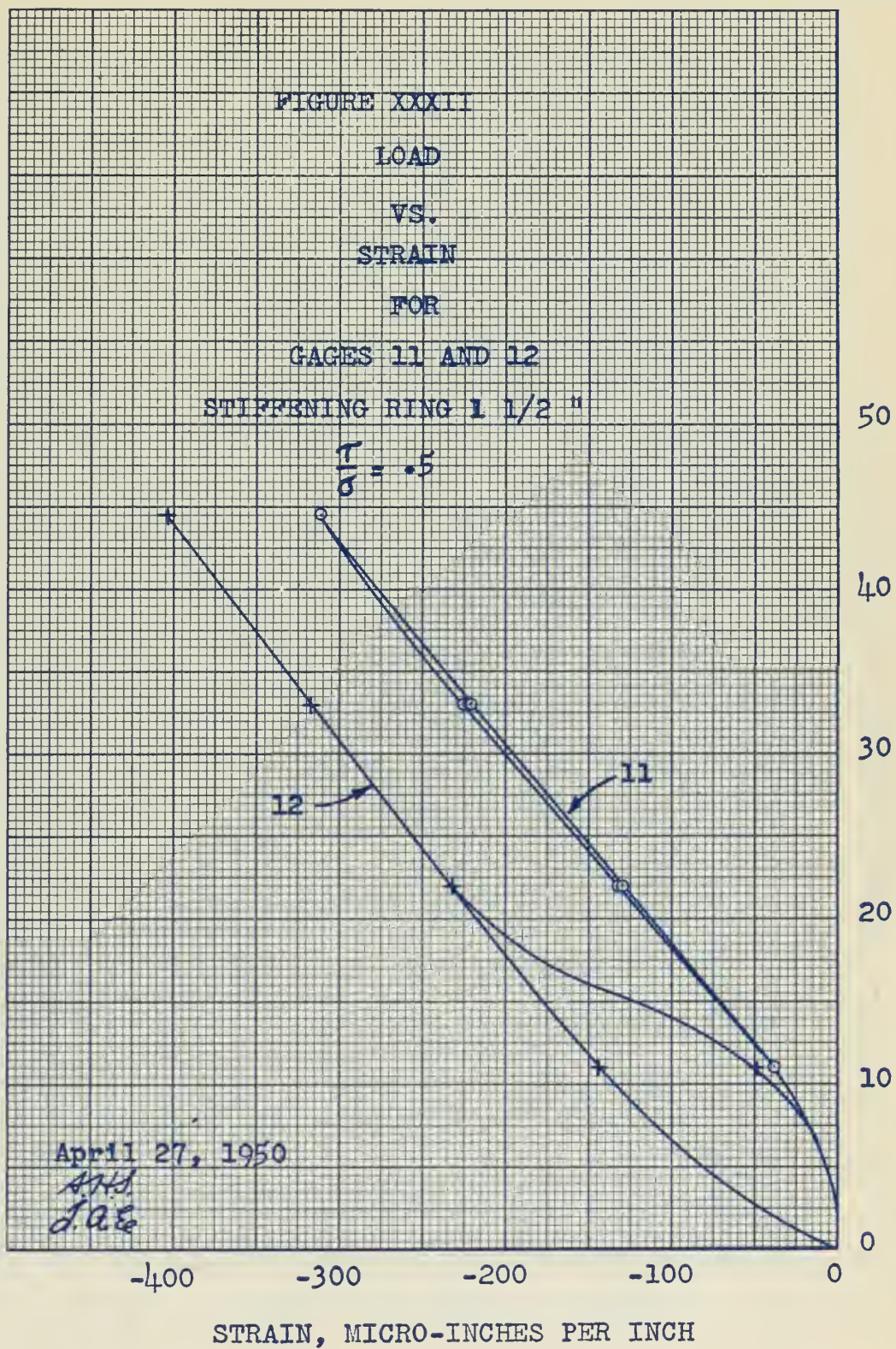






Figure XXXIII

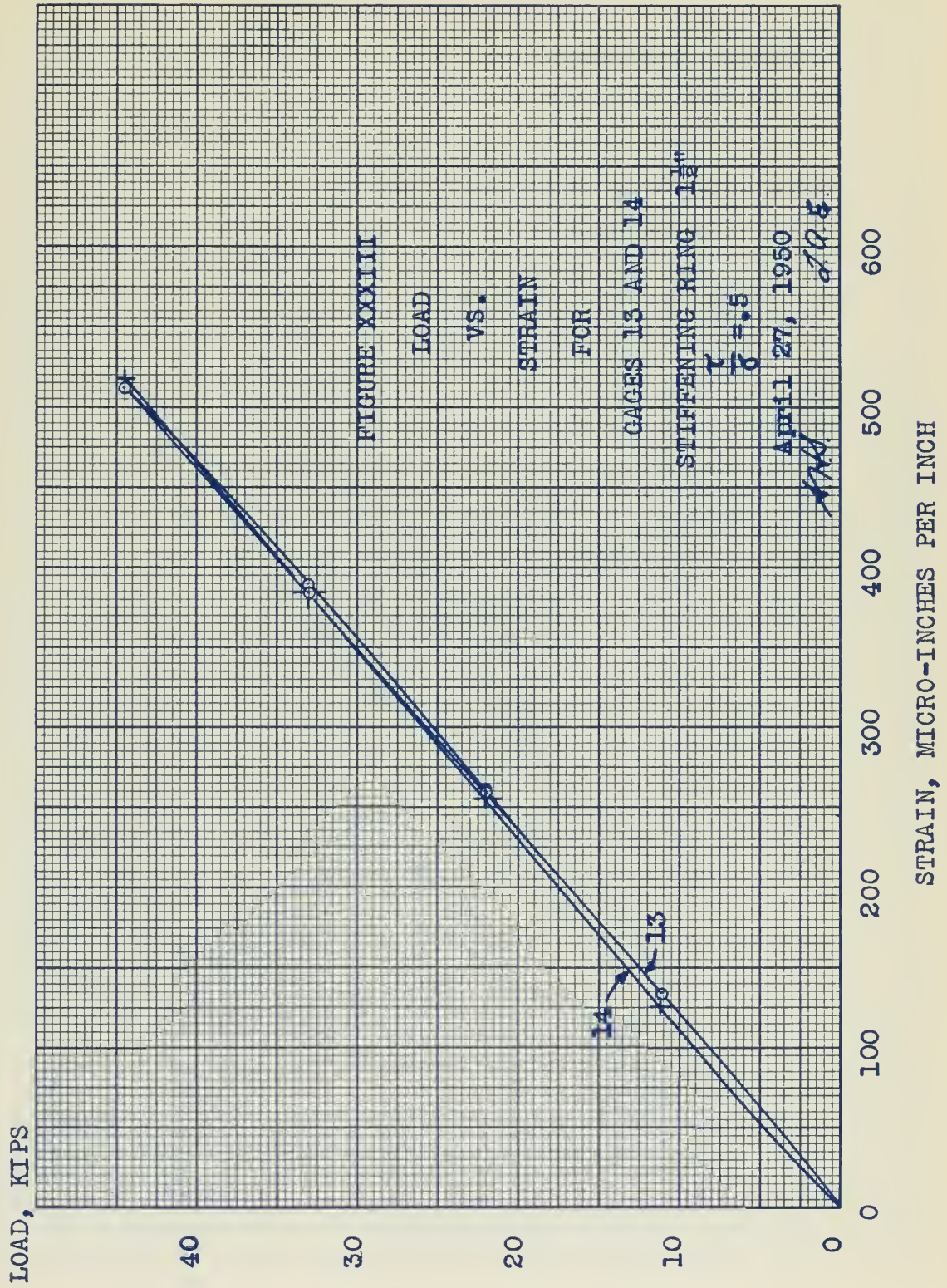






Figure XXXIV

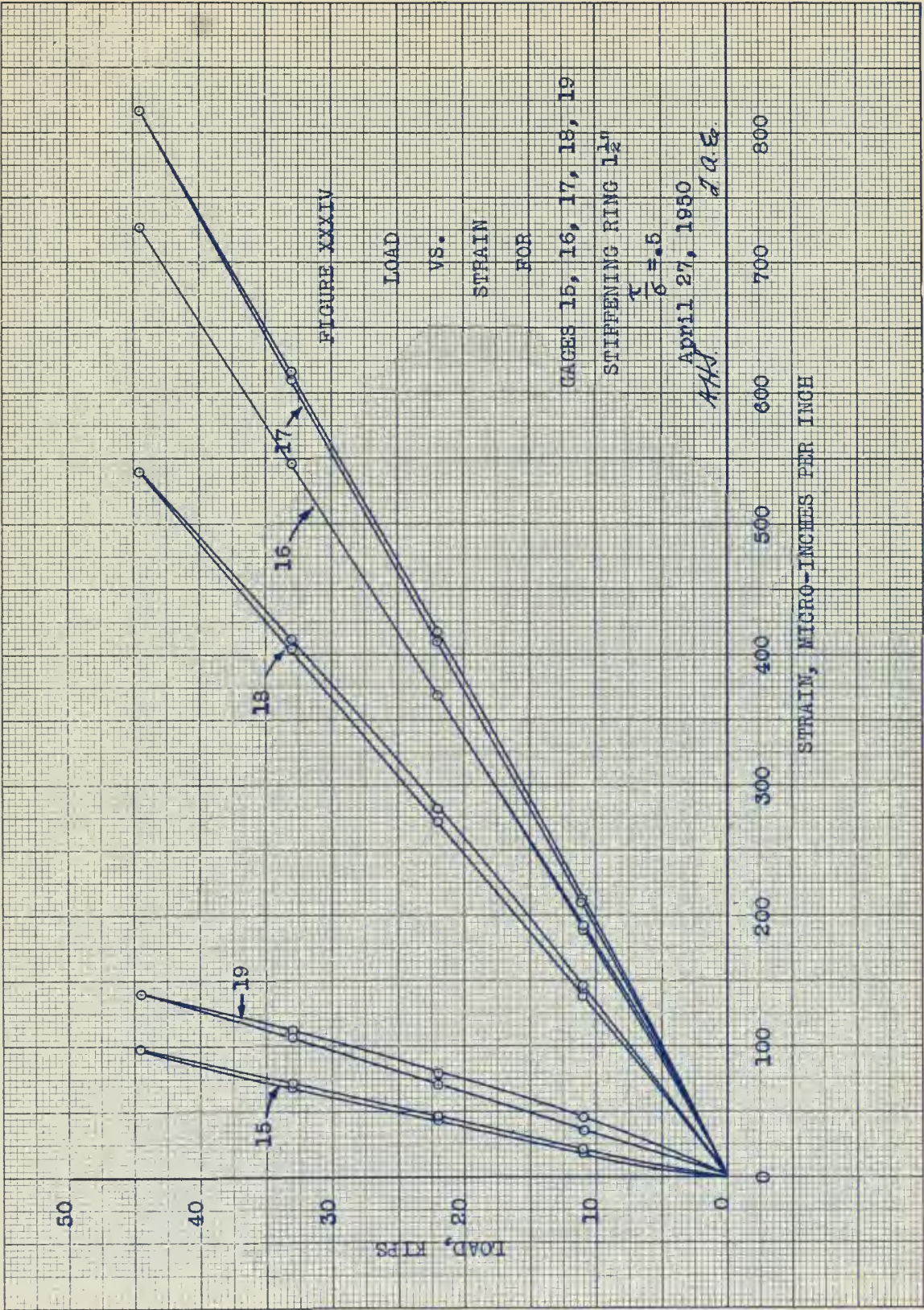






Figure XXXV

LOAD, KIPS

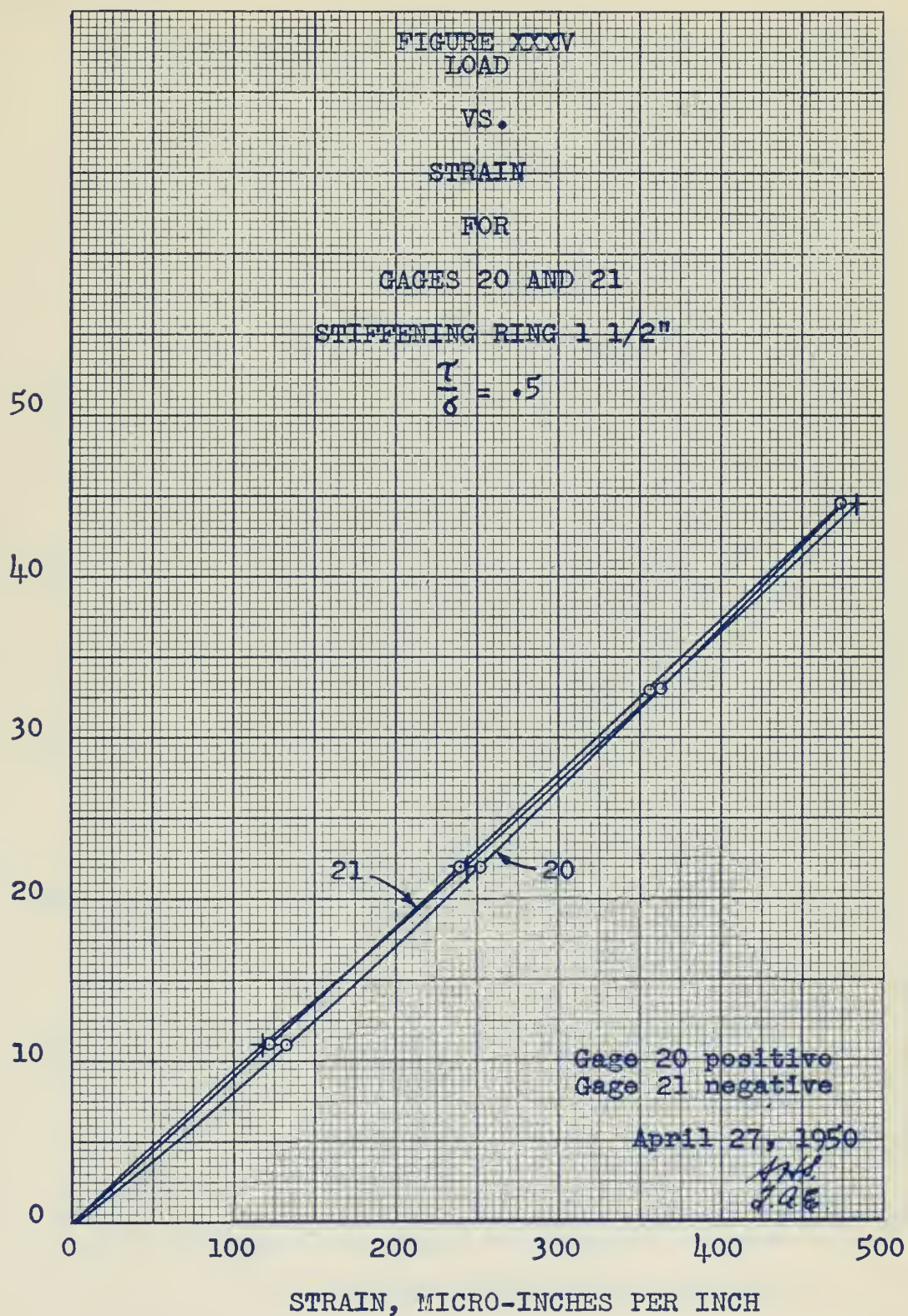






Figure XXXVI

LOAD, KIPS

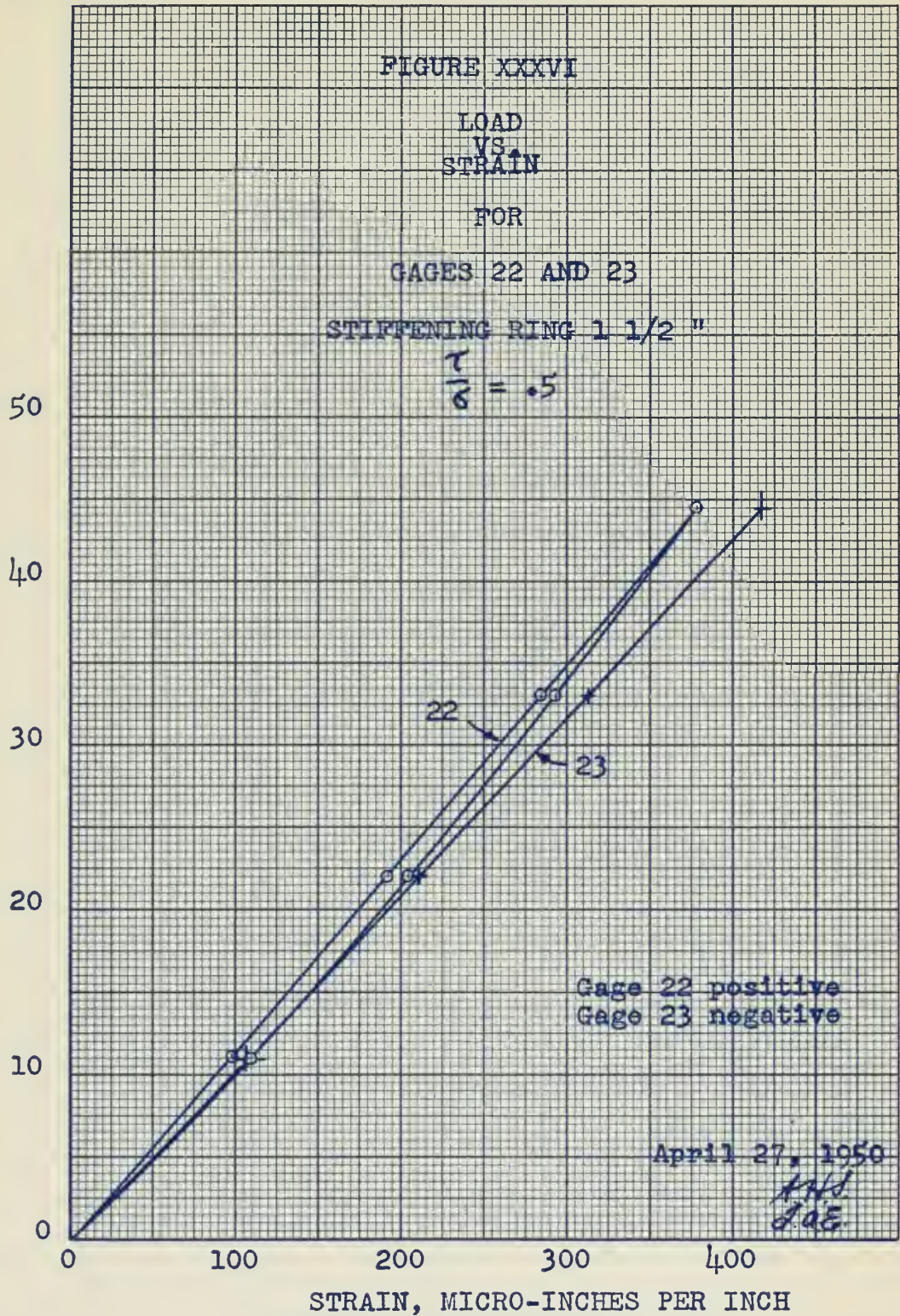






Figure XXXVII

LOAD, KIPS

FIGURE XXXVII

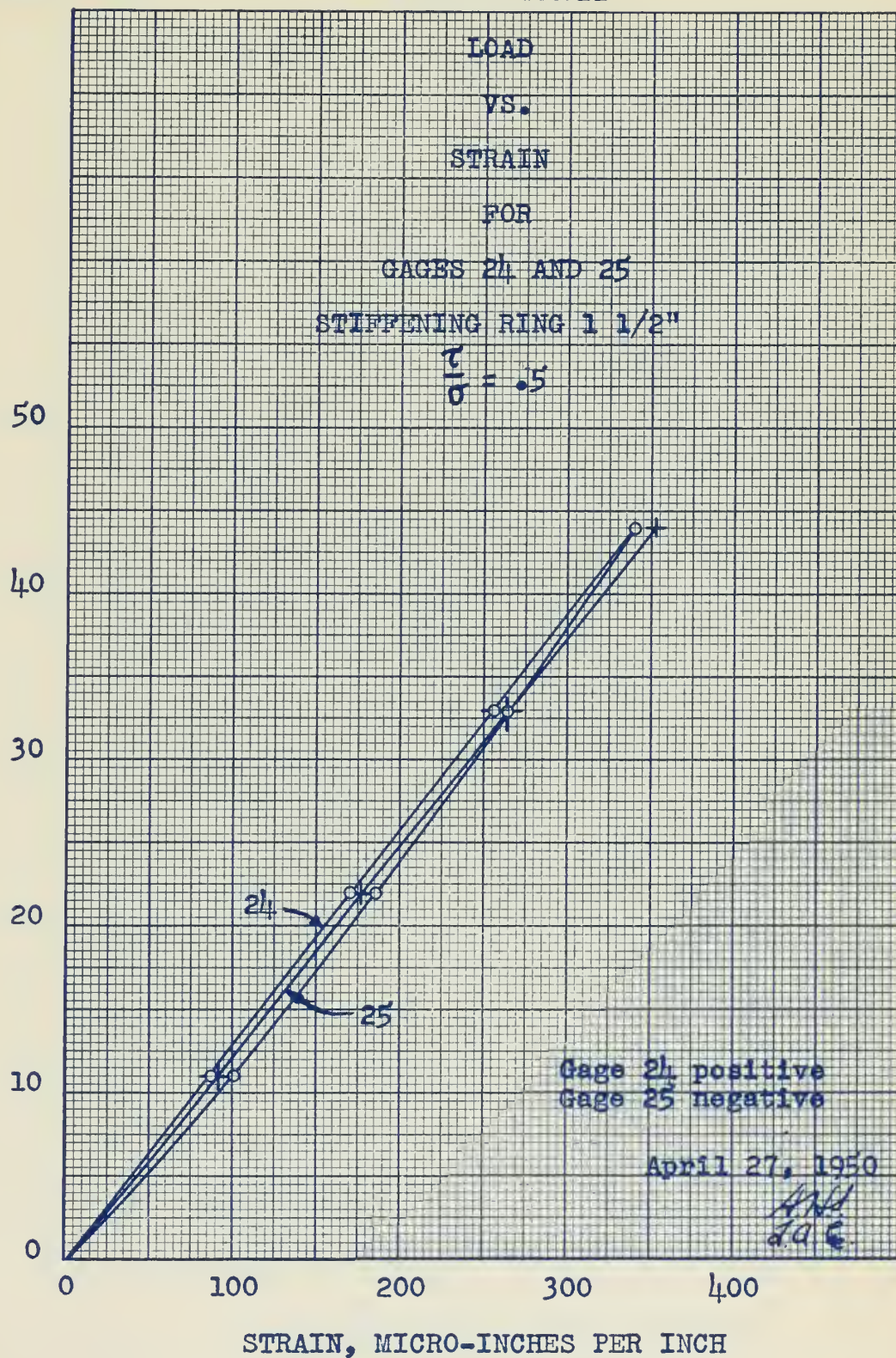






Figure XXXVIII

LOAD, KIPS

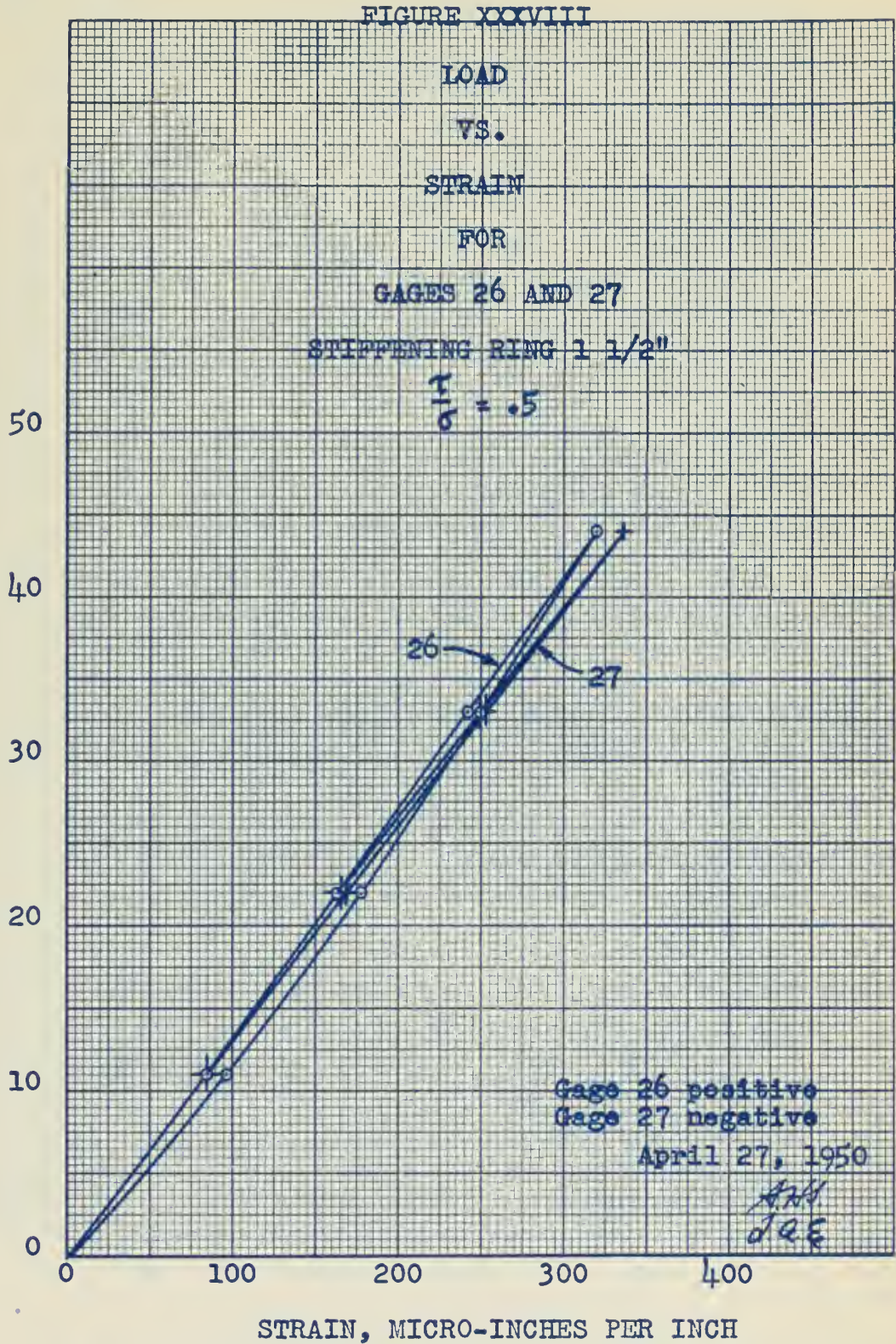


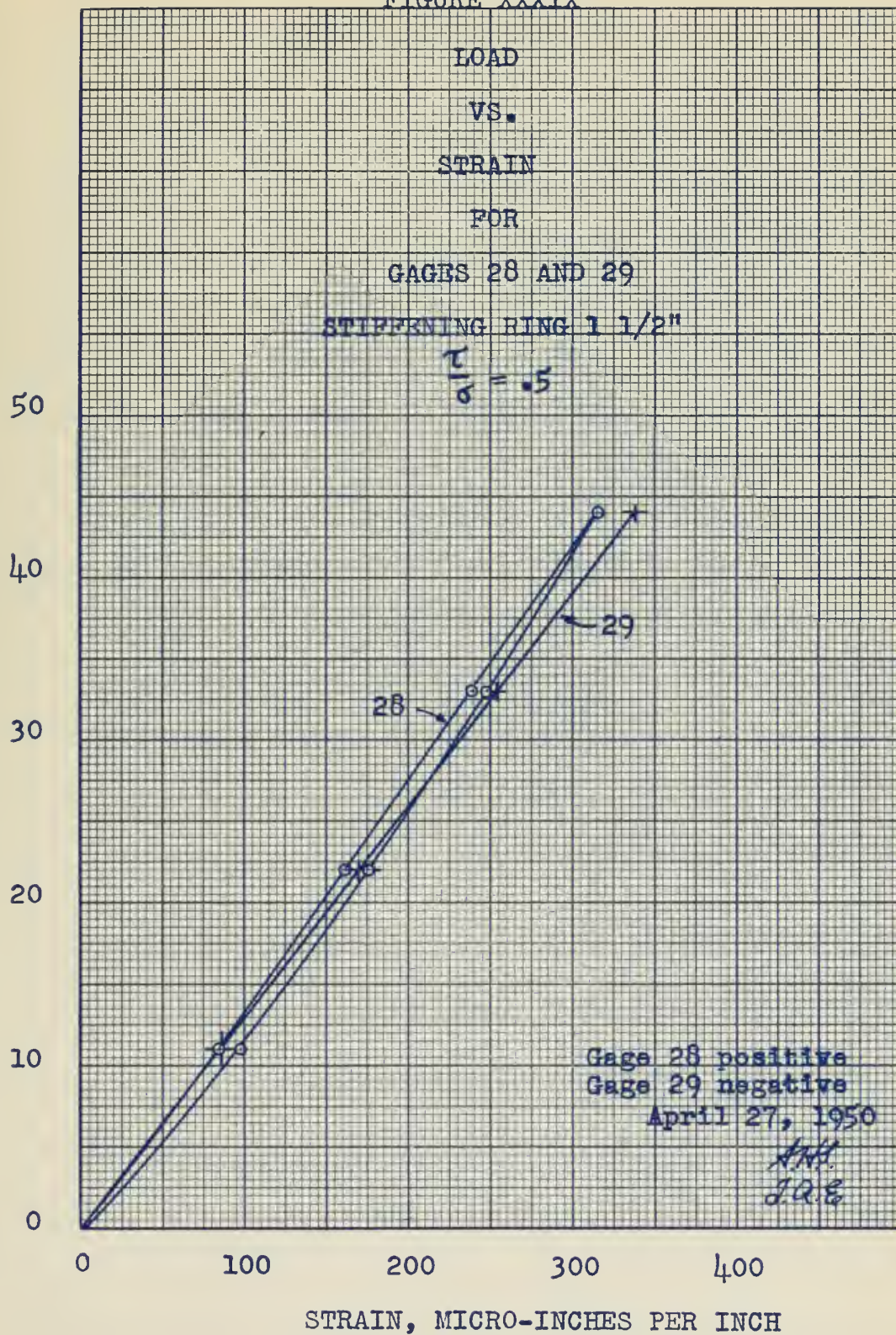




Figure XXXIX

LOAD, KIPS

FIGURE XXXIX





### TENSILE TEST OF MATERIAL

Two flat plate test specimens were prepared in accordance with the specifications of the A. S. T. M., one from an excess portion of the original beam, the other from material corresponding to that used in the flat bar stiffening ring. These were tested in a 60,000 pound Baldwin-Southwork hydraulic testing machine. Huggenburger Tensometers were attached to the specimens and readings of strain were made at each load. From the load vs. strain plot of each specimen, Figures XL and XLI, the modulus of elasticity and the approximate yield point were obtained.

The multiplication ratios for the Tensometers were as follows:

No. 69	325
No. 71	330





TABLE XIII

TENSILE TEST SPECIMEN CUT FROM  
STEEL BEAM

Load, Lbs.	Huggenburger Readings		Avg. Reading	Elongation $\times 10^3$
	H - 69	H - 71		
1000	.02	.03	.025	.077
2000	.05	.065	.0575	.176
3000	.08	.10	.090	.275
4000	.12	.125	.1225	.375
5000	.15	.155	.1525	.466
6000	.175	.180	.1775	.543
7000	.21	.21	.21	.642
8000	.24	.24	.24	.735
9000	.26	.26	.26	.795
10000	.30	.30	.30	.9175
12000	.355	.355	.355	1.085
14000	.425	.415	.420	1.235
16000	.48	.47	.475	1.453
17000	.52	.50	.51	1.560
17700	.55	.52	.535	1.637
17500	.55	.51	.53	1.620
17200	1.20	1.20	1.20	3.67

Area of cross section 0.361 sq. in.

Approximate yield load 17,700 Lbs.

Approximate yield point 49,000 psi.

Modulus of Elasticity  $30.3 \times 10^6$  psi.



Figure XL

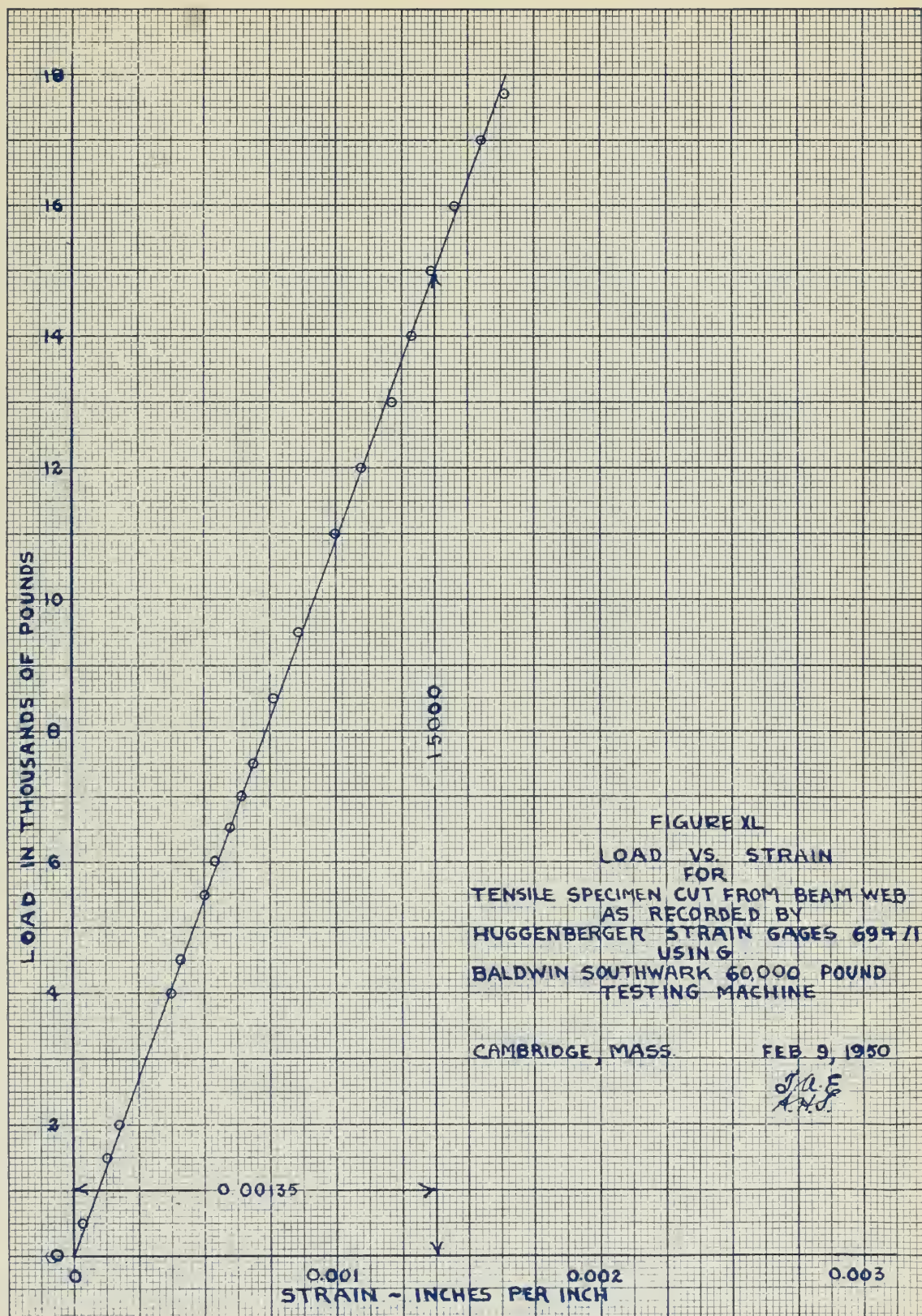






TABLE XIV

TENSILE TEST SPECIMEN  
CUT FROM FLAT BAR

Load,	Huggenburger Readings		Average Readings	Elongation $\times 10^3$
	H - 69	H - 71		
0	-.10	-.10	-.10	-.0306
1000	-.08	-.12	-.09	-.0275
2000	-.05	-.10	-.08	-.0245
3000	-.03	-.07	-.05	-.0153
4000	-.00	-.05	-.025	-.0076
5000	.02	-.04	-.02	-.0061
6000	.05	.00	+.025	+.0076
7000	.07	.01	.04	.0122
8000	.10	.045	.0725	.0222
9000	.145	.05	.0825	.0252
10000	.150	.08	.115	.0352
12000	.19	.145	.167	.0512
14000	.23	.180	.205	.0670
16000	.275	.230	.252	.0772
18000	.33	.27	.30	.0917
19000	.35	.280	.315	.0963

Area of cross section .500 sq. in.

Approximate yield load 19000 Lbs.

Approximate yield point 33,000 psi.

Modulus of Elasticity  $28.28 \times 10^6$  psi.

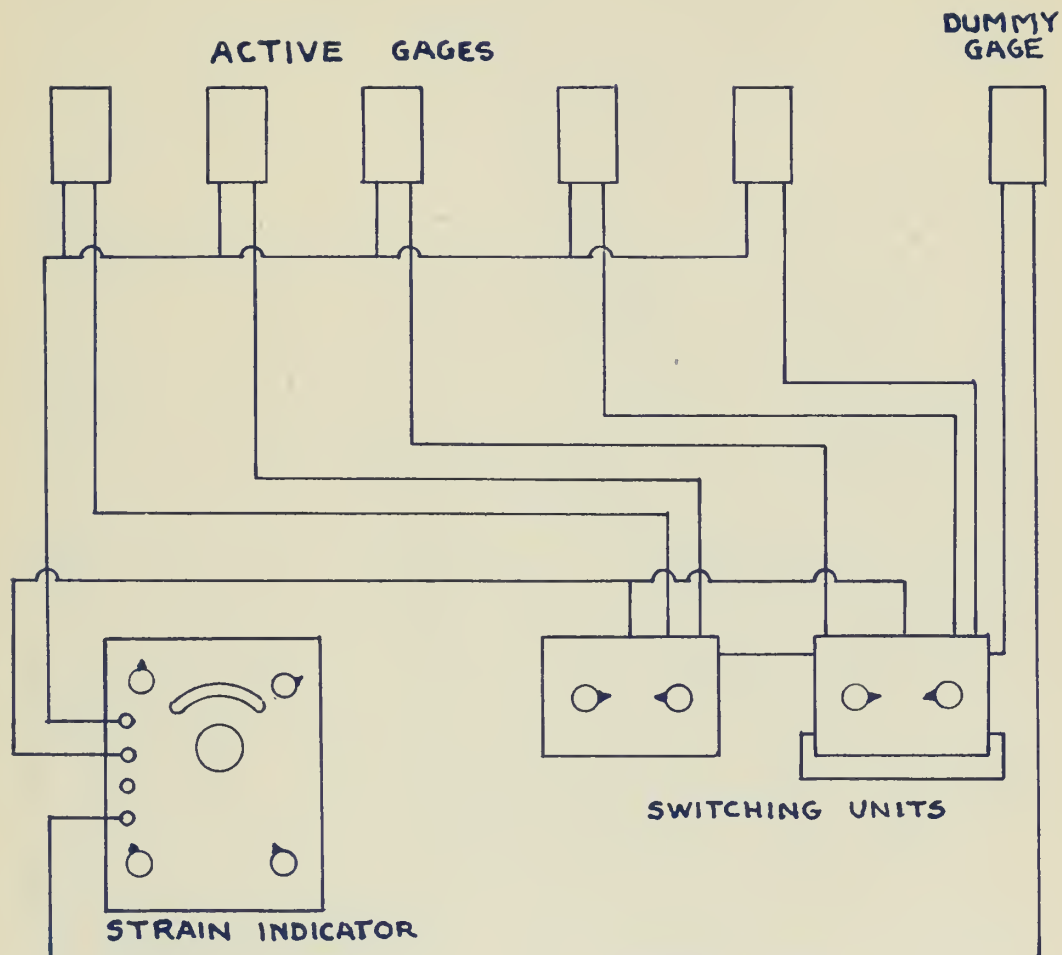








FIGURE XLII



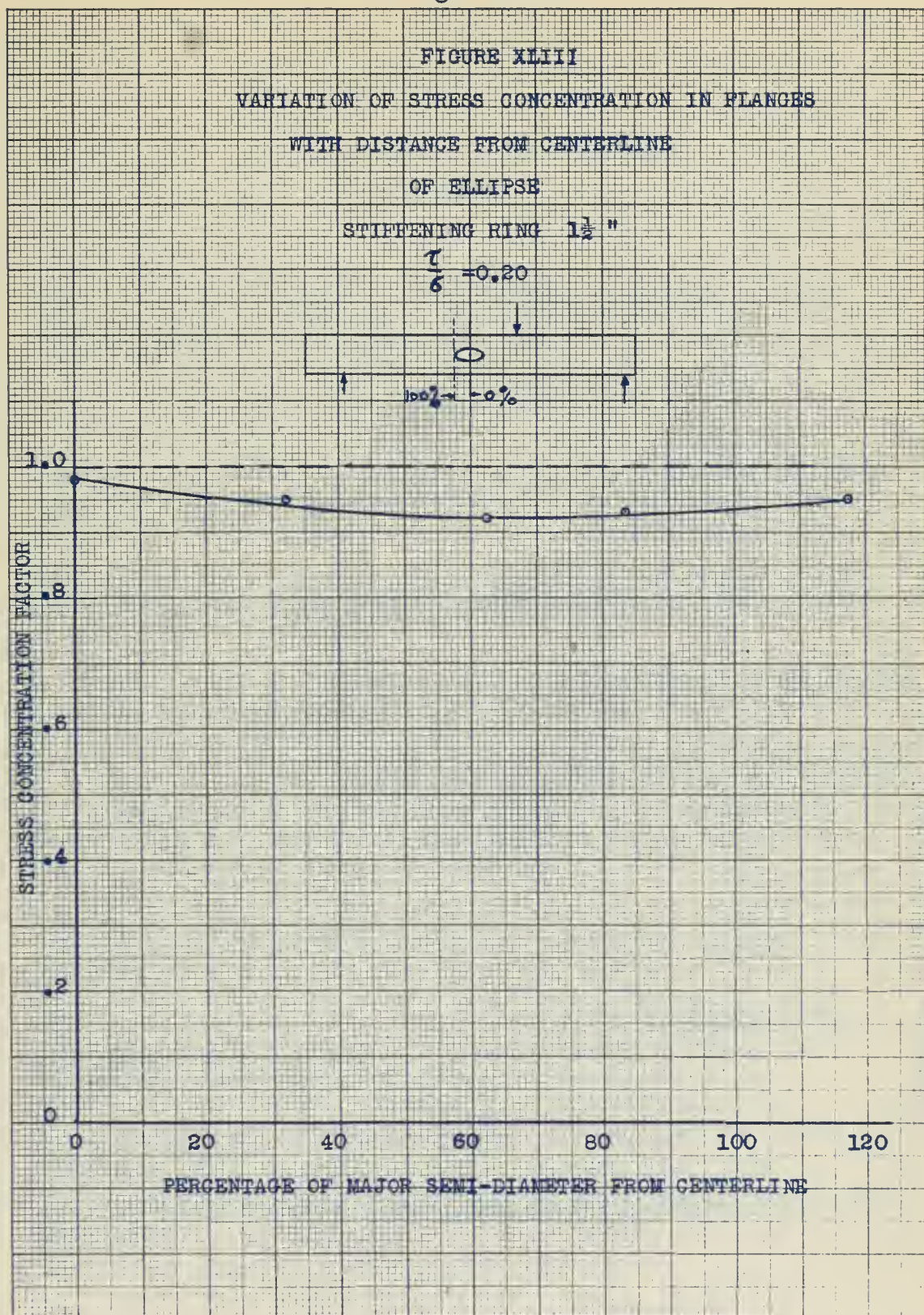
WIRING DIAGRAM  
FOR  
STRAIN GAGES AND INSTRUMENTS

APRIL 29, 1950  
J.A.E. *K.W.J.*





Figure XLIII







## APPENDIX E

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## DATE DUE

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Thesis

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Stress concentration  
in a beam with a rein-  
forced elliptical dis-  
continuity.

Thesis

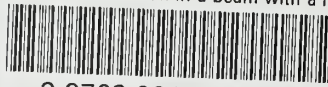
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Stress concentration  
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